Cb SHALE OIL VENTURE

ASHLAND COLORADO, INC.

OCCIDENTAL OIL SHALE INC., OPERATOR

Cb TRACT

PICEANCE CREEK BASIN

RIO BLANCO COUNTY, COLORADO

HYDROLOGY, MINE DEWATERING AND WATER USE AND AUGMENTATION

AUGUST 1977

TIPTON AND KALMBACH, INC.
ENGINEERS
DENVER, COLORADO

Cb SHALE OIL VENTURE

ASHLAND COLORADO, INC.

OCCIDENTAL OIL SHALE INC., OPERATOR

Cb TRACT

PICEANCE CREEK BASIN

RIO BLANCO COUNTY, COLORADO

HYDROLOGY, MINE DEWATERING AND WATER USE AND AUGMENTATION

AUGUST 1977

TIPTON AND KALMBACH, INC.

ENGINEERS

DENVER, COLORADO

CONTENTS

TABLES

FIGURES
(following text)

Cb TRACT
Piceance Creek Basin
Rio Blanco County, Colorado

HYDROLOGY, MINE DEWATERING AND WATER MANAGEMENT

August, 1977

INTRODUCTION

In early 1974, the U.S. Department of Interior issued a lease on a 5,100 acre parcel of land in the Piceance Basin, Rio Blanco County, Colorado, known as the Cb Tract. The lease was for the purpose of developing the oil shale known to be present. It was originally planned that the material would be mined underground by room and pillar methods and retorted on the surface; subsequently, after three of the original partners in the lease retired, planning was changed to utilize an "in situ" method of development.

As now contemplated, development of the operation will begin in late 1977 and full scale production of about 57,000 barrels of oil per day will be reached 5 to 6 years afterward. The working level in the mine will vary with location on the tract, but will start at about 1250 to 1750 feet below the surface. The water table is 300-400 feet deep, and the rocks below that level are saturated.

In order to recover the shale oil in the Cb Tract, the area must be sufficiently dewatered to such a level within the working area to allow mining the retorts and to allow combustion. The water brought to the surface during dewatering and processing must be consumed or otherwise disposed. Piceance Creek, the flow of which consists primarily of groundwater that emanates through springs and seeps along its course, lies just to the north of Cb Tract. Dewatering of the mine will alter the groundwater regime of the surrounding area and hence may affect to varying degrees vested water rights, most of which are currently utilized for irrigation of narrow strips of land along Piceance Creek and some of its tributaries. These effects may be manifested by a diminution in surface water supplies through either the drying up of springs or an increase in channel losses and a lowering of water levels in wells. The quality of surface and groundwater supplies may also be affected. All of

these effects and the measures taken to alleviate them will be related to the quantity, quality, and rate of extraction of water from the mine; the quantity and quality of water consumptively used in operations at the site; the quantity and quality of water which is surplus to such use and must be disposed; the method and location of disposal; the time required after completion of mining operations for the groundwater to return to pre-mining levels; and changes in the groundwater system which may be found after mining ceases.

The studies described herein were undertaken to examine the foregoing matters as they relate to the Cb Tract and to devise a suggested water management plan for preliminary planning purposes. These included an evaluation of the hydrology of the area, estimates of the amount of water that will have to be pumped to dewater the mine and the amount and quality of water to be disposed of, and an evaluation of the effect of such operations on vested water rights. The various kinds of works that may be required to implement the plan for water management are described only in conceptual terms and no detailed design of facilities and works has been undertaken as a part of this study. No new field investigations have been carried out; rather free use has been made of the data, studies, and findings of numerous prior investigations carried out by agencies of the federal government, state, universities, and the lease holders and consultants retained by them, most of which are listed in the References at the end of this Report. Those sources most often referred to herein include the Lessees (Occidental Oil Shale, Inc. and Ashland Colorado, Inc.). The United States Geological Survey (U.S.G.S.), The Ralph M. Parsons Company (Parsons), Colorado State University (Wymore), Energy Consulting Associates (ECA), and the law firm of Davis, Graham, and Stubbs (D.,G.&S.).

THE PICEANCE CREEK BASIN

The Piceance Creek drainage basin is located in the northern portion of the Piceance Creek structural basin, which extends from the Colorado River to the White River, mostly in Rio Blanco County (Figure 1). The drainage basin is enclosed on the south by the Roan Plateau and on the west by the Cathedral Bluffs at altitudes of over 8,000 feet. On the east and north the enclosing ridges range from 8,000 feet to about 6,500 feet in elevation. Piceance Creek empties into the White River at about elevation 5,700 feet. Topography within the drainage basin is typified by northeast-southwest trending, relatively steep-sided valleys eroded into a plateau, creating local relief of 200 to 600 feet.

The climate of the area is semi-arid. Annual precipitation at the Little Hills station in the lower valley averages about 13 inches. As is typical in the mountainous areas of Colorado precipitation generally increases at higher elevations, and in the Piceance Creek basin probably averages 25 inches per year or more at elevations above 9,000 feet. Although average rainfall amounts over an extended period of time indicate relatively little seasonal variation in precipitation, it is difficult to project data from an individual station to large areas because of the marked effects of topography and exposure and the generally limited area covered by local storms, particularly during the summer.

Temperatures within the basin range from about -40°F in the winter to nearly 100°F in the summer. Frost-free days vary from about 120 in the lower valleys to 50 days per year at the higher altitudes.

Narrow strips of land along Piceance Creek and some of its tributaries, used for raising hay and pasture, are irrigated during the summer. Water is diverted from the stream by numerous small ditches for flooding the hay and pasture lands, often at annual rates of 3 to 5 acre-feet per acre when supplies are available. Most of such water returns to the stream relatively quickly and the annual water depletion due to irrigation is no more than about 1.5 acre-feet per acre at elevations below 6,000 feet and perhaps one-third of that amount at 7,500 feet elevation.

Geology

The surficial and near-surface rocks of the basin are a thick sequence of sedimentary deposits of Tertiary age, with Quaternary alluvium filling the deeper valleys. Figure 2 shows typical stratigraphic columns and cross sections across the Tract. Only the upper Green River and Uinta Formations and the alluvium are germane to this discussion.

a. Green River Formation: The formation is divided into three members, the Douglas Creek, Garden Gulch, and Parachute Creek. The sediments forming the Green River Formation were deposited in a structurally-formed lake during Eocene time and contains, in its upper member, the important oil shale deposits of the region.

The Parachute Creek Member is about 1,600 feet in thickness at the Cb Tract. The member is composed largely of dolomitic marlstone which contains kerogen (oil shale), as well as zones in which the saline minerals halite, nahcolite, and dawsonite are found.

The Parachute Creek member has been grossly subdivided into a "high resistivity" or unleached zone, a "leached zone", the Mahogany zone or upper oil shale zone, and the section above the "A groove" which is a lean oil section at the top of the Mahogany Zone. The "B groove" is a similar lean horizon at the base of the kerogen-rich Mahogany zone. Subdivision based on hydrocarbon content has also been made below the B groove, dividing the lower oil shale zone into richer (R) and leaner (L) units. (Figure 3.)

At the depositional center of the basin, halite, nahcolite, and dawsonite were deposited in the lower Parachute Creek member. The Cb Tract lies on the southeastern portion of this depositional environment. Some nahcolite still exists beneath the western part of Cb, but below the zone of the mine. Considerable evidence of leaching of soluble minerals is found from the mid-Mahogany Zone downward. Dawsonite is found in minor amounts throughout the oil shale section.

Above the "A-groove" is about 300 feet of lean oil shale extending to the base of the Uinta Formation. Near the top of the section is a 40-foot zone known as the "Four Senators", an aquatard which is commonly quite impermeable.

b. Uinta Formation: The Uinta Formation is the surficial rock over the entire interior portion of the Piceance Creek drainage basin. It is composed of tan-to-gray sandstones, siltstones, and mudstones with some marlstone. Since the top of the formation has been eroded, the total thickness is not known; about 1100 feet of Uinta Formation is present on Cb Tract.

c. Alluvium: The Piceance Creek Valley and its major tributaries are filled to stream levels with Quaternary alluvium which has been derived from the Uinta Formation. Sand, gravel, and clay comprise the material which reaches thicknesses exceeding 100 feet in the main valley.

The Piceance Creek structural basin occupies the area from roughly the Colorado River to the White River and from the Grand Hogback in the east to Cathedral Bluffs on the west. The basin is a broad closed syncline with structural relief of about 4,000 feet within the area of interest. Several small folds are present within the basin, having NW-SE trending axes, and some NW-SE trending high angle normal faulting has been mapped to the northwest of Cb. The deepest part of the basin lies about 15 miles NNW of the Cb Tract.

HYDROLOGY

The hydrology of the Piceance Basin is exceedingly complex. Most of the visible flow in Piceance Creek and its tributary streams consists of groundwater discharge which originated from precipitation over the higher portions of the watershed, supplemented in the spring by surface runoff from melting snow and occasional rainstorms in the summer. In this environment climate, physiography, and geology strongly influence the seasonal pattern, quantity, and quality of groundwater and surface runoff. And, during the summer much of the flow of Piceance Creek and a few of its tributaries is diverted into ditches for irrigating hay and pasture lands in the stream valleys.

The mining of oil shale will have an impact on the groundwater regime and depending on location, the mode of dewatering and water management will affect the flow of surface streams. An understanding of the hydrology of both surface and groundwater and the interrelationships between the two is essential to an evaluation of the effect of future developments on the water resources of the basin.

Surface Water

It is estimated that a weighted average of about seventeen inches of precipitation falls annually on the 630 square miles drained by Piceance Creek, ranging from an average of about 10 inches per year at its confluence with the White River up to more than 25 inches at elevations above 9,000 feet in the headwaters of the basin. Most of this precipitation evaporates or is transpired by vegetation soon after it falls, part is temporarily stored at higher elevations in the winter snowpack which melts during the following spring producing surface runoff and recharge to groundwater. Part of the groundwater recharge eventually is discharged through springs and seeps in the stream valleys where it mingles with surface runoff and part is transpired by native vegetation in bottomlands lying a few feet above the water table. More than 110 ditches along Piceance Creek and some of its tributaries divert most of the summer flow of the streams. Only a relatively small portion of the water diverted by these ditches is actually consumed by the irrigated crops; the balance accrues to the stream as return flow to be again diverted by ditches lower down in the valley. As a result, less than 1/40th (about 0.4 inch) of the precipitation falling on the watershed actually flows out of Piceance Creek into the White River.

Apart from the fact that there are no long-term records of precipitation in the upper portion of the basin and the records of streamflow at stream gaging stations within the basin (see Figure 1) are of short duration, the problem of quantitatively describing the hydrology of surface water flow is compounded by the facts that:

1. None of the gages reflect the natural (or virgin) flow during the summer because of upstream irrigation diversions or diversions by ditches which bypass the gaging stations.

2. During much of the year, the quantities of flow are small and difficult to measure.

3. During the winter the flow of some springs and seeps is transformed into ice and some gages are affected by icing conditions.

4. The setting off of the Rio Blanco Project underground nuclear blast in May of 1973 drastically increased the rate of groundwater discharge in parts of the basin with the result that runoff is apparently only now slowly beginning to return to the regime which existed prior to the blast.

The longest period of streamflow record that can be considered to reasonably represent predevelopment conditions is that of the station on Piceance Creek below Ryan Gulch, which was established in September 1964. The station near the mouth of the Creek at the White River has little more than 4 years of streamflow records prior to the blast, and records of all other gaging stations within the basin are of even shorter duration.

Notwithstanding these difficulties, Wymore (1974) undertook an evaluation of the hydrology of the basin using a water balance approach. With estimates of precipitation, temperature, and other climatic factors he developed estimates of evapotranspiration losses for the basin. Taking into account types of vegetation, elevation, aspect and slope of the lands, he arrived at an average annual water balance which produced an estimated average annual outflow remarkably close to the eight-year average annual flow derived from gaging station records. While the values derived by that study are intended only

to represent long-term average annual values, it nevertheless provides an excellent picture of the relative importance of the major factors which influence the hydrology of the basin. Wymore's results are summarized in the following tabulation:

	Average Annual Amounts (acre-feet)
Total precipitation on watershed	583,713
Portion of rainfall evaporated and transpired (annual change in soil moisture assumed to be 0)	559,830
Net water production (or yield) consisting of surface runoff and deep percolation (recharge)	23,883
Water consumed by:	
Evapotranspiration in high water table areas (11,900 acres)[(a)]	4,879
Irrigated crops (5,100 acres)	5,902
Total water consumption	10,781
Net outflow to White River	13,102
Eight year (1965-72) average annual flow of Piceance Creek at its mouth	13,377[(b)]

(a) Referred to in Wymore's report as "sagebrush run-in, seep, and phreatophyte" areas.

(b) Derived by correlation with gage below Ryan Gulch and adjusted for diversions which bypass station.

It is of interest to note that most of the basin water yield of about 24,000 acre-feet per year originates from areas above about 7,000 feet in elevation, or above Cb Tract, as shown below from Wymore's data:

Elevation Zone (feet)	Area (acres)	Surface Runoff and Recharge: Acre-feet/year	Surface Runoff and Recharge: Inches/year
> 9000	900	311	4.15
8 - 9000	56,600	13,257	2.80
7 - 8000	206,400	9,788	0.57
6 - 7000	135,900	527	0.05
< 6000	2,800	0	0
	402,600	23,883	0.71

In contrast about 90 percent of the water consumption by irrigation and transpiration in high water table areas takes place below 7,000 feet in elevation.

The 24,000 acre-feet of average annual water yield is made up of groundwater discharge and surface runoff. Surface runoff, which may have large variations from year to year, is composed primarily of the spring snowmelt supplemented at times by runoff from summer thunderstorms, usually of limited areal extent. Groundwater discharge reaches the stream through springs and seeps and does not vary as greatly in amount from year to year as does surface runoff. Differences in the character of the flow pattern and chemistry of various springs lead to the conclusion that some springs drain the main aquifers of the region. Others show a seasonal pattern of flow akin to that of surface runoff, indicating that they are supplied from "perched" aquifers or receive their recharge from areas near their outlets. Some springs have their sources in a deep aquifer as shown by the chemical composition of the flow. Sufficient data are not available to be certain of those springs which derive their flow from aquifers above or below the regional piezometric surface.

For purposes of this study, it is sufficient to catalog the water yield of the basin as being made up of two components, as follows:

a. The base, or relatively constant, year-round flow, having relatively small variations from year to year, plus

b. Seasonal flow, consisting primarily of surface runoff from snowmelt and groundwater discharge from perched or semi-perched aquifers.

Examination of hydrographs of the recorded flow at gaging stations within the Piceance and adjacent basins provide insight into the relative magnitude of the above flow components. Figure 4 shows a hydrograph of the flow of Piceance Creek at the gaging station below Ryan Gulch and monthly precipitation measured at Meeker. It is readily apparent from examination of these data that:

1. Although precipitation forms the original source of all streamflow, there is no readily discernible relationship between the two, other than perhaps

the low runoff in 1967 and 1972 may have been due to subnormal precipitation during the preceding year. It is possible that if data on the amount of precipitation over the higher elevations of the watershed were available, a better correlation might be evident. But the accumulation of snow during the winter and the subsequent slow movement of groundwater from areas of recharge to the stream valleys make the opportunity of detecting a direct correlation between rainfall and runoff somewhat remote.

2. The underground nuclear blast of Project Rio Blanco which took place on May 17, 1973, so disrupted the rocks through which groundwater flows as to cause a relatively large increase in the discharge of seeps and springs. While the effects of this blast were apparently attenuated with greater distances from its epicenter and there is some evidence that the rate of groundwater discharge to streams is slowly returning to pre-blast conditions, streamflow data subsequent to May 1973 are not considered to be representative of the long-term hydrologic conditions. For this reason, except where otherwise noted, the parameters cited herein refer to the pre-blast hydrologic environment.

3. Streamflow rises more or less rapidly near the end of February and in March as surface runoff from snowmelt reaches the stream, but drops rapidly in April as water is diverted by ditches for the initial flooding of pasture and hay lands.

4. From April through October, streamflow is generally at a low level because of irrigation diversion above and around the gaging station, but fluctuates widely because of local rains and/or the closing and opening of ditch headgates.

5. During the winter months of November through February, most of the precipitation occurs as snow, all irrigation has ceased, evapotranspiration losses are relatively small, and streamflow, consisting almost entirely of groundwater discharge, is relatively constant.

The flow of Piceance Creek recorded at the gage near its mouth at the White River exhibits the same characteristics as the gage below Ryan Gulch shown in Figure 4. Figure 5 shows hydrographs of the flow of Piceance Creek at several stations upstream from Ryan Gulch gage during periods for which records are available. Because of irrigation diversions, the general pattern of flow is similar to that of the gage below Ryan Gulch; but as expected the higher the gage is in the basin, the more pronounced is the spring snowmelt runoff because of the lesser amount of area irrigated above the station. At the old station at Rio Blanco, having only 9 square miles of drainage area, the flow consists almost entirely of surface runoff with very little base flow.

Figure 6 shows hydrographs of several springs, selected to illustrate their varying characteristics of flow. Spring No. 123 on Fawn Creek not far from the 1973 blast site is indicative of the marked changed in discharge which took place at that time. The seasonal pattern of flow of this spring, however, was not significantly altered. Spring No. 133 on Willow Creek is typical of springs which exhibit relatively little seasonal fluctuation inflow. Here the effect of the blast can also be seen, but is apparently attenuated because of its greater distance from that event. Spring No. 111 near the mouth of Black Sulphur Creek is typical of the springs showing consistent seasonal variations in discharge. It also reflects to a modest degree the effect of the underground detonation. Spring No. 136 on the Middle Fork of Stuart Gulch shows a tendency toward a seasonal variation in runoff displaced in time from that which would be expected from a truly perched aquifer and probably derives its flow from an aquifer with a distant source of recharge.

Of particular interest is the hydrograph of the flow at the gaging station on Miller Creek near Meeker, depicted on Figure 7. The Miller Creek Basin is situated to the east of the Piceance Basin (Figure 1) but has the same general orientation with respect to the path of prevailing winter storms, andgenerally similar physiography. The area above the gaging station is relatively small, higher in elevation than the Piceance Basin, and hence receives more precipitation. Some general comparisons of the Miller Creek Basin with that of Piceance Creek above Ryan Gulch follow:

		Piceance Creek Above Gage Below Ryan Gulch	Miller Creek Above Gage Near Meeker
Drainage area	sq mi	485	57.6
Mean elevation of basin	ft	7,310	8,450
Elevation of gage	ft	6,070	6,710
Runoff measured at gage:			
acre-feet/yr		10,890[a]	14,150[b]
inches/yr		0.42	4.60

(a) Average of 8 years (1965-72) prior to blast not adjusted for diversions past station

(b) Average of 6 years (1971-76)

While a few irrigation ditches divert water above the Miller Creek gage, the areas irrigated and irrigation depletions are both much less than in the Piceance Basin because of the higher altitude and shorter growing season.

It may be noted that the flow of Miller Creek is composed of an essentially constant year-round base flow component (which seldom varies more than two or three second-feet throughout the year) plus a snowmelt component during May and June.

It is believed that, if it were possible to construct hydrographs of the virgin flow of Piceance Creek, unaffected by irrigation diversions, it would follow a pattern very similar to that of Miller Creek with the surface runoff component of flow appearing a month or two earlier because of the lower elevation of the Piceance Basin. By analogy it can be hypothesized that the true base flow component of the flow of Piceance Creek is represented by the measured discharge during the normally stable winter flow period from November through February. For the nine winters of "pre-blast" recorded flow at the gage below Ryan Gulch the base flow averaged about 15.6 cfs. For the 5 winters of concurrent "pre-blast" records of flow at the White River station the gain in streamflow between Ryan Gulch and the lower station averaged 4.4 cfs. Although a small amount of irrigation return flow may be reflected in this "gain" it is estimated that the average annual base flow component of Piceance Creek at its mouth is in the order of 20 cfs or about 14,000 acre-feet per year.

By integrating this estimate of average base flow in the earlier estimate of average annual water yield, and making appropriate adjustments for annual variations it is estimated that the water production and runoff of Piceance Creek under present conditions falls within the range of values indicated in Table 1.

Table 1

Estimated Annual Water Production
and Runoff of Piceance Creek Basin
Under Present Conditions
(all values in acre-feet)

	Year of Subnormal Runoff	Year of Average Runoff	Year of Above normal Runoff
Water Production:			
Base flow component	10,000 °	14,000 °	19,000 °
Seasonal flow component	7,000	10,000	14,000
Total	17,000	24,000 •	33,000
Water Consumption:			
By native vegetation	4,000	5,000 •	6,000
By irrigated crops	5,000	6,000 •	7,000
	9,000	11,000 •	13,000
Net Discharge or Outflow to White River	8,000 °	13,000 •°	20,000 °

In the preceding table the values marked (•) are derived primarily from Wymore's water balance studies. The values marked (◦) are derived from streamflow records. All other values are based largely on judgement to fit the totals of derived values. While the unmarked values might be subject to question they could not depart greatly from the amounts indicated without disturbing the overall hydrologic relationships which are believed to prevail.

The foregoing discussion and the values indicated in Table 1 refer to conditions which prevailed before the Rio Blanco nuclear detonation of May 1973. As mentioned earlier, that blast resulted in a significant increase in groundwater discharge in various areas of the basin. For example, the winter base flow at the gage below Ryan Gulch

has increased two-fold to an average of about 32 cfs since 1973 and, curiously, historic winter gains between Ryan Gulch and the mouth of the Creek have disappeared. Whether this is due to inherent errors in measuring small differences in discharge between two points, or some other factor, is not known. While it is suspected that the groundwater system is gradually returning to its "pre-blast" regime, much more data and study will be needed to arrive at firm conclusions.

Surface Water Quality

The quality of water in Piceance Creek is typical of streams in semi-arid climates, being of marginal quality according to optimum standards for municipal use. Nevertheless, water from the stream and alluvial wells has been used for many years for irrigation, stock watering, and domestic use without significant detrimental effects.

The quality of the streamflow deteriorates in the downstream direction, owing to groundwater discharge and irrigation return flow. Figure 8 shows the relationship between total dissolved solids and streamflow at four stations on Piceance Creek. The two lowermost curves on this Figure represent stations short distances above and below the Cb Tract, indicating a significant increase in the dissolved solids in this relatively short reach of four miles. The increase is even more marked between Ryan Gulch and the mouth of the creek where water from the more saline lower aquifer is discharged through several small springs.

Total dissolved solids, sodium adsorption ratio (SAR), and fluoride and boron are the parameters of greatest interest in judging the suitability of the water for irrigation purposes. Within the usual range of summer flows, data collected to date indicate that the present quality of water in Piceance Creek in the vicinity of Cb Tract falls in the following range of values:

		Station 6007	Station 6061
Total Dissolved Solids (TDS)	ppm	550-800	600-1100
Fluoride (F)	ppm	0.2-1.3	0.3-1.3
Boron (B)	ppm	0.1-0.3	0.1-0.5
SAR[a]	-	2-3	2.5-3.5

[a] $SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$ with constituents expressed in meq/l

Groundwater

Study of the groundwater resources of the Piceance Basin began in the early 1960's as a result of the realization of the importance groundwater must play in oil shale development. In 1972 the U. S. Geological Survey, in cooperation with the Colorado Department of Natural Resources, undertook a comprehensive investigation of the hydrology of the basin which included the watersheds of both Yellow Creek and Piceance Creek. For this purpose, two digital models were developed — a watershed model and a groundwater hydraulics model — to simulate the hydrologic system. The results of those studies are contained in U.S.G.S. Professional Paper 908 (Weeks, et al, 1974). In the discussion which follows, data contained in that report has been utilized both for information and for comparison with results of this study of a small part of the entire area.

Over 100 exploration wells have been drilled with aquifer tests performed on several of them. On the Cb Tract alone, about 30 wells have been drilled, and another 15 or more are within a short distance of the Tract boundaries. Aquifer testing at the Tract has been limited to one-day pumping tests on alluvial wells, so-called mini-pump tests using packers to isolate various sections to be tested, and two long-term pumping tests with a number of monitored points. Most of the wells tested by "jetting", or air-lifting were performance tests, and aquifer data obtained by this method are not considered representative. Drill stem tests were run on three wells; again the results are only qualitative.

There are large quantities of groundwater in storage in the Piceance Creek drainage basin. The Parachute Creek member of the Green River Formation contains the greatest volume because of its thickness, porosity, and position in relation to the water table. With insignificant development of groundwater, the basin is in equilibrium; outflow through evapotranspiration, streams, and underflow generally balance recharge to storage. Estimates of groundwater storage in the basin as a whole range up to 25 million acre-feet.

Groundwater occurs throughout the Piceance Creek Basin at depths ranging from the surface in some stream valleys to as much as 500 feet on higher ridges. Both the Uinta and Parachute Creek Formations are water-bearing. Owing to epigenetic cementation in the Uinta and to the lithology of the Parachute Creek, primary porosity is low, and the effective porosity is largely secondary, the result of fractures and solution of primary minerals.

Groundwater flow direction is controlled and defined by the geologic structure as indicated by the piezometric surface map compared to the structure contour map. Recharge entering the aquifer in the highlands surrounding the basin flows toward Piceance Creek, the course of which closely follows the axis of the main synclinal structure. Discharge is from springs and through the deeply incised alluvium of Piceance Creek.

The water-bearing materials can be separated into three zones, a lower aquifer, an upper aquifer, and the alluvial aquifer. The alluvial aquifer is essentially unconfined, the upper aquifer apparently is grossly unconfined with some semi-confined zones. The lower aquifer is well confined; upward leakage from the lower aquifer is apparently occurring through structural fractures and open wells.

a. The alluvial aquifer: The major stream valleys are filled with gravel, sand, and clay which represent detritus from the surrounding Uinta Formation. Thicknesses of up to 140 feet of alluvial fill have been reported. Near the Cb Tract, the Piceance Creek Valley has over 100 feet of fill while Willow Creek and Stewart Gulch alluvium extends 60 or more feet below the existing surface. The alluvium is heterogeneous. Water yield to wells is dependent upon the permeable material encountered and the areal extent of such lenses.

b. The upper aquifer: The stratigraphic section from the Mahogany Zone to the surface is lumped as the upper aquifer. The upper part of the aquifer is comprised of the Uinta Formation and the lower part of marlstones of the Parachute Creek.

   Permeability in the upper aquifer is mainly due to fracture porosity; precipitation of secondary minerals in the sandstones has largely filled the primary voids. Generally the lean marlstones in the lower part of the aquifer are more brittle and therefore more susceptable to fracturing than are the sandstones, thus the more conductive section of the aquifer is in the lower part of the unit. While the aquifer in gross acts as an unconfined aquifer,

owing to the secondary porosity, short-term pumping tests indicate confined conditions. Overall vertical leakage, however, should be effective in long-term pumping.

Two water bearing zones are regularly found over the Cb Tract, a zone beneath the "Four Senators" about 200 feet above the "A Groove", and at the A Groove itself. These lean oil zones are significantly more fractured than the enclosing rocks. In only one well on the tract was there significant flow from the Uinta.

Several lean to medium kerogen-rich zones, which impede water movement vertically and horizontally, occur locally in the interval 300 feet above the Mahogany bed. Where identified on the geophysical logs, these zones have been named the "Twins" (10 feet thick), the "Big Three" (5 feet thick), and the "Four Senators" (40 feet thick). About 20 feet above the top of the Mahogany Zone is a 15-foot permeable zone or aquifer (A Groove) which has increased the yield from 20 to 150 gpm in every borehole in which the flow was logged. On the basis of flow tests within the boreholes, at least six and sometimes seven zones of higher permeability have been identified. Below the A Groove, the Mahogany bed, rich in kerogen, is an impermeable zone which acts as an aquaclude. Pumping tests have indicated the vertical permeability of the Mahogany Zone to be extremely low; generally the waters above and below that zone are remarkably different in chemistry, another indication of the effective separation of the upper and lower aquifers.

c. Lower aquifer: The lower aquifer of the area comprises the Parachute Creek Formation below the top of the Mahogany Zone. Fracture porosity is important and is enhanced by solution of primary minerals, principally nahcolite. The lower Mahogany Zone has marked evidence of solution. The "leached zone", or body of rock from which soluble minerals have been leached, is the most prolific aquifer in the basin. Below the leached zone is a "high resistivity" zone from which the saline minerals have not been leached, and which exhibits very low permeability.

On the Cb Tract the Mahogany Zone is an interval of rich oil shale 174 to 187 feet in thickness, having the hydraulic property of impeding the flow of water. The U.S.G.S. assumed that a relatively thin section within the zone acts as the confining layer, but evidence from temperature and specific conductance logs indicate a zone possibly 150 feet thick may be restricting the movement of water. The zone is bounded on the bottom by a permeable zone called the "B Groove."

Detailed mapping of the top of the Mahogany Zone indicates the Cb Tract lies on the south limb of the Hunter Creek syncline whose axis lies immediately beyond the north edge of the Tract. The general slope is northward 425 feet in $2\frac{1}{2}$ miles. Within the Mahogany Zone major joints sets strike N72°W and dip 40°-45°NE. Vertical joints are generally absent. Jointing and fracturing reflect the different structural properties of the sandstones and shales and the degree of kerogen enrichment, in that the rich parts are less brittle and deform without fracturing under stress. Consequently the richer zones are more likely to restrict movement of water.

The confining ability of the Mahogany Zone is confirmed by the difference in levels at which water stands in tightly cased holes tapping the formations above and below, where a difference of about 50 feet has been observed; highest levels occur in the formations above the Mahogany Zone.

Below the Mahogany Zone the formations are similar to those above except for the saline deposits remaining from the depositional stages. Groundwater circulation over a long period of time has partially removed some of the soluble sodium salts leaving a leached zone of higher permeability above the unleached zone. Three saline minerals - nahcolite ($NaHCO_3$), dawsonite ($NaAl(OH)_2CO_3$), and halite (NaCl) - occur throughout the basin, but are concentrated in the depositional center to the northwest. There all three occur, sometimes in lenses, but most often intermixed, and occupying up to one-fourth of volume of the 1000-foot interval at the base of the Green River Formation. Outward from the center of the basin, the halite diminishes in concentration and thickness, and farther toward the edges the nahcolite also diminishes. Dawsonite does not occur 4 to 6 miles south of the Tract. In the Tract area dawsonite is present, and small amounts of nahcolite are found in the western part of the Tract in the lean shales.

The leaching and partial removal of the nahcolite by percolating groundwater moving down dip to the center at the basin, has enchanced several permeable layers for easier water movement. The upper leached zone whose thickness is about 300 feet, includes the "B Groove" aquifer (80 feet thick) immediately below the Mahogany Zone, and extends to the base of the L-5 Zone.

The lower leached zone or basal aquifer in the Parachute Creek, also about 300 feet thick, is mostly oil shale but includes a lean zone about 90 feet thick that is more permeable than the adjacent shales. The bottom of the lower aquifer and the base of the lower leached zone is a series of richer shales which are considered to be impermeable. The base of the proposed mining on the tract is about 400 feet above the base of the lower leached zone.

The levels of the water in each formation and whether they are the same or different affects the program of pumping and disposal of the drainage water. The U.S.G.S. mapping of the generalized potentiometric surface in the basin shows movement, from altitudes of 7200 feet at the southern and southwestern edges of the basin northward, somewhat paralleling the surface drainage of Piceance and Yellow Creek to an altitude below 6,000 feet where the stream drainages enter the White River. That mapping also noted that the level, or head, of water in the deeper formations in the central part of the basin stands higher than the level in the shallow formations, indicating opportunity for upward leakage where the confining layer is breached. At the southern and western edges of the basin the water level stands higher in the shallow formations and thus downward flow is probable. The area of equal potential in the shallow and deep formations is beyond the south edge of the Cb Tract.

The Cb Tract

Recent exploration and data on the Tract indicate the head relations in the underground formations are variable with depth and location, and in general, the saturated mass of formations is very heterogeneous. The water levels in the upper aquifer show the direction of flow of groundwater is from NNE to NNW from altitude 6,705 at SG-21 to an altitude of 6,380 feet at SG-19 (Figure 9).

The dominate shape of the water table surface in the upper aquifer is a groundwater mound rising 30 to 50 feet above the parallel surface drainage of Stewart Gulch on the east and Willow Creek on the west. Minor indentations in the mound occur at Sorghum and Cottonwood Gulches. Although details are lacking, the mound apparently disappears on the north side in the Piceance Creek channel.

If the upper aquifer were homogeneous, it would appear in this simplified model that the aquifer feeds the streams and the interconnection would permit movement in either direction. Limited data on pairs of wells in the alluvium and in the upper aquifer (SG-19 & A-7, SG-8 & A-9, Cb4 & A-12, SG-1 & A-3) indicate the water levels in the alluvium are below those in the upper aquifer, and the fluctuations in each are neither similar in amount, nor rise or fall in unison. Conclusions to be drawn from these data are that the aquifer probably contributes to the surface drainage above the stream level, but if the upper aquifer head were lowered considerably below the stream level, the seepage from the stream would not be great.

The variation in head in the upper and lower aquifers appears to be related to the height of the groundwater mound in the upper aquifer. The largest difference in head in the upper over the lower aquifer of 45 to 55 feet occurs at SG-6 and SG-11 near the highest part of the mound. Smaller differences of 10 to 15 feet occur at SG-17 and SG-9 and very little difference is found at SG-1 at the edge of the mound. These conditions suggest a hydrologic system in which the lower aquifer obtains most of its recharge from some distance south of the Tract, and with no interflow through the confining Mahogany Zone, the local recharge to the upper aquifer builds up additional head and flow, creating the groundwater mound.

Where the static water level has been observed in the Mahogany Zone only (AT-1c), the level is one foot higher than in the lower aquifer and 30 feet lower than in the upper aquifer.

Several exploration holes extended below the proposed level to be mined in the middle of the Green River formation have measured static levels in the basal and the lower aquifer. In SG-1 the level in the basal aquifer is essentially the same as the upper and

and lower aquifers. This may be coincidental because adjacent holes open to several formations may have had allowed interformational flow which permitted all to reach a mutual equilibrium.

The anomalous static water levels in the area confirm the nonhomogeneity of the formations and the flow of water through them. The levels indicate two major aquifers on the Tract not necessarily interconnected on or near the Tract, but at some remote distance. The nonhomogeneity indicates caution should be exercised in using rates of flow and times for drainage predicted on the basis of average or uniform properties of the aquifer. Physical or mechanical problems in drainage are not considered to be serious on the Tract, but the volume and timing are of concern because of utilization and disposal.

Groundwater Quality

The quality of the groundwater in the Piceance Creek Basin ranges greatly, both with geology and geographic location. Generally speaking, the quality deteriorates in the direction of flow toward the center of the basin, and the upper aquifer water is of better quality than the deeper part of the lower aquifer. In the Mahogany Zone, the water is generally better than the average of either the lower or upper aquifers.

Streamflow quality also deteriorates in the downstream direction, owing to groundwater discharge and irrigation return flow. Discharge from the lower aquifer to the stream is present from Ryan Gulch to the White River. Faulting presumably is responsible for allowing lower aquifer water to come to the surface.

a. Alluvial groundwater quality. The quality of water derived from alluvial wells near the Cb Tract ranges from less than 1000 ppm total dissolved solids in wells into tributary alluvium, to over 1200 ppm in the main Piceance Creek Valley. The waters are typically mixed bicarbonate - sulfate types with sodium adsorption ratios (SAR) of four to six. Fluoride content ranges from less than 0.2 ppm to 2 ppm in one well. Wells in the Piceance Creek alluvium near Ryan Gulch yield over 5000 ppm TDS, with high NaCl (SAR 100).

b. Spring flow quality. Spring water quality ranges from quite good to extremely poor. Near the Cb Tract, TDS range from about 800 ppm to nearly 1200 ppm with SAR = 0.5 to 4.5. Near the mouth of Piceance Creek, however, springs are reported carrying over 20,000 ppm TDS, essentially all $NaHCO_3$. Those highly mineralized springs apparently are draining the lower aquifer, while the Cb area springs, mixed HCO_3 and SO_4 waters, are from the Uinta. Fluoride content of the higher springs is generally about one ppm, while the water rising from the lower aquifer carries 20 ppm or more.

Quality of water data are not available for most of the springs in the area; it is probable that water quality ranges widely from those stated above. It is believed that springs have various sources - alluvial, perched aquifers within the Uinta, from the upper Parachute Creek, as well as from the lower aquifer. Some have high seasonal variation and therefore probably yield water which has had little time of contact and distance of travel. Others have essentially uniform flows, indicating longer contact time in the aquifer.

c. Upper aquifer quality. With some exceptions, water samples collected from the upper aquifer by wells on and near the Cb Tract are of relatively good quality. Analyses indicate the "typical" water to be a HCO_3/SO_4 mixed type, SAR ranging from about 3 to 8, containing from 0.1 to 9.0 ppm fluoride.

Several wells, however, yield much poorer quality water than is considered typical. On the southeastern corner of the Tract, and also in two wells 1/2 mile north of the tract, samples of water from the upper aquifer are low in SO_4, have a high SAR (30 to 50), and high fluoride. In one of these, SG-17, it was known that the well was leaking upward, and the well was reworked and plugged back, resulting in higher quality discharge. The other two wells, SG-19 and SG-20, are artesian and yield warm water with lower aquifer chemistry. It is probable that these wells have been contaminated by leakage from below. Such leakage might occur either through the well itself or through local fracturing, but no additional evidence of fracturing contributing to leakage has been seen on Cb Tract.

While samples obtained from wells with screened sections in the upper aquifer generally contain fluoride content of a few ppm or less, in one well on which drill stem test samples were taken, fluoride content consistently runs 10 to 15 ppm in the upper Parachute Creek aquifer. In addition, analysis of drilling water from some of the early wells on the tract shows fluoride content of about 20 ppm in the composite samples obtained. Thus, the information regarding fluoride content in the upper aquifer is clouded. The water from the upper aquifer test on well AT-1 increased from 3 ppm to 18 ppm during pumpage. It seems likely that higher fluorides than indicated by samples from the cased wells is to be expected.

The average of the "upper aquifer" samples available on the Cb Tract contains about 1.3 ppm boron. Drill stem test samples from SG-17 yielded somewhat higher values, but, as mentioned above, SG-17 is an anomalous well, so that the meaning of the differences is unclear.

d. Lower aquifer quality. The water from the lower aquifer varies greatly with depth. Samples taken within the Mahogany Zone contain 700-800 ppm TDS, somewhat less than the upper water. The waters are bicarbonate type with SAR 9 to 10 owing to the lack of Ca and Mg rather than to an excess of sodium. Boron is present in about 1 ppm and fluoride is in the range of 15 ppm. Below the mining zone, brines have been encountered which are extremely high in sodium, bicarbonate, and chloride. In SG-11, a sample from the upper aquifer contained 1130 ppm TDS, 868 ppm from the Mahogany Zone, and nearly 40,000 ppm from a 900 foot section beginning about 100 feet below the B Groove and extending to the bottom of the Parachute Creek member. SG-9, which is only 100 feet higher in the lower aquifer section, has only about 1850 ppm, while SG-10 yielded 42,000 ppm from a perforated section starting

about 100 feet below the top of the Mahogany Zone to just below the B Groove. When the well was plugged below the Mahogany Zone, the water was found to contain only 2800 ppm. Again, it is unclear whether the extremes are related only to horizontal variation or whether vertical leakage is largely responsible.

Typical waters from the lower aquifer have 800 ppm to 3000 ppm TDS, contain more chloride than the upper waters, but are essentially of sodium bicarbonate type. SAR ranges from 15 to over 100 and probably averages about 40. Fluoride is in the 15 to 30 ppm range, and boron is reported to range from less than 1 ppm to 10 ppm.

Aquifer Characteristics

Knowledge of the ability of the individual formations to release the water from storage and transmit the flow to collecting structures for drainage is needed to determine the rate of flow and the time required for dewatering in order to schedule the mining operation on the tract. This knowledge has been obtained from detailed testing with flow meters and packers, and with aquifer pumping tests for some of the exploration holes. Values for the aquifer coefficients - transmissivity, permeability, storage, and sometimes leakance - for the area of the tests were determined. As might be expected in formations whose composition varies greatly, the aquifer coefficients cover a wide range. However, when the total thickness of the upper or lower aquifer is considered as a unit, the transmissivity is in the expected range for this type of sandstone- marlstone material.

Transmissivity is expressed in gallons per day per foot (gpd/ft) and is defined as the rate of flow in gallons per day through a foot wide prism of the saturated thickness of the aquifer under unit gradient at the prevailing temperature. Average permeability in gallons per day per square foot is transmissivity divided by saturated thickness.

The coefficient of storage is defined as the water released from storage per unit volume per unit decline in head. It should be noted that the value of the coefficient of storage will vary according to the conditions of the occurrence of groundwater and

the time during which it has been draining. Thus, it is not a constant value. In a deep, or semi-confined aquifer, the water released is first obtained by elastic compression of the aquifer structure, or expansion of the water itself, when the pressure is reduced by the drawdown in the well; under these conditions the coefficient of storage is a small decimal fraction. In a water table aquifer, or a semi-confined aquifer where drainage has progressed sufficiently, water is released from storage by gravity drainage; the coefficient of storage under these conditions is equal to the specific yield, which commonly ranges from 0.05 to 0.15 for these materials.

Leakance is the vertical permeability of an aquitard, and is expressed as units of flow through a unit area per unit gradient. Although leakance values are very small decimal fractions, the gradients are very large and under some conditions, over large areas for example, the total volume of leakage can be significant. Unlike what was reported by the U.S.G.S. for the basin as a whole, testing on the Cb Tract revealed essentially no leakage through the Mahogany Zone.

Table 2 lists the coefficients of transmissivity and storage as determined by testing on the Cb Tract. Much of the variation in the measured aquifer coefficients is attributed to the properties of the formations, but some can be due to construction of the test wells which were not screened, or were open to all of the vertical section of the aquifer. Many of the larger coefficients were obtained from observation wells, where the more reliable determinations are made. Directional orientation of permeability was observed with a 10-fold increase in the northeasterly direction. After averaging the transmissivity determinations from all the tests and weighing the directional trends, it is believed the areal transmissivity of the upper aquifer is about 1500 gpd/ft, which is 0.7 of the value used by the U.S.G.S. for the area including the Cb Tract.

Analysis of aquifer tests of the formations below the Mahogany Zone indicate non-homogeneous conditions similar to those in the upper aquifer, and with directional components of permeability also similar to the upper aquifer. Although the range in measured values of transmissivity in the lower aquifer is wide, there are many values bracketed at about 400 gpd/ft, which is believed to be a reasonable value for the section to be drained. This value is about one fourth of that used by U.S.G.S. for the area including the Cb Tract.

Table 2

Aquifer Coefficients from Pump Tests

Well Number (String #)	Transmissivity gpd/ft	Storage Coefficient (dimensionless)
Upper Aquifer		
AT-1a(#3)	1140	4.23×10^{-4}
AT-1b	1210	3.71×10^{-4}
AT-1c	960	2.73×10^{-4}
AT-1d(#3)	970	2.97×10^{-4}
SG-6	1590	1.68×10^{-3}
SG-10	1740	4.21×10^{-4}
SG-11	1160	6.92×10^{-5}
32X-12	1250	not available
33X-1	940	not available
Lower Aquifer		
AT-1a(#1)	328	4.19×10^{-4}
AT-1c(#1)	306	1.21×10^{-5}
AT-1c(#2)	153	1.22×10^{-4}
AT-1d(#1)	265	2.67×10^{-5}
SG-6(#1)	687	5.30×10^{-4}
SG-6(#2)	267	6.48×10^{-5}
SG-10(#1)	110	3.92×10^{-5}
32X-12	300	not available
33X-1	380	not available

As stated previously, during an aquifer test the water discharged by a pumped well is derived from storage through; 1) gravity drainage, 2) compaction of the aquifer structure or, 3) expansion of the water itself as pressure is released at the well. However, gravity drainage is often not immediate, especially in fine-grained heterogeneous formations. Under such circumstances, the water is not released from storage instantaneously and the aquifer shows the time-lag phenomenon of delayed yield. Delayed yield is a term applied to the process within the aquifer where the intercalated layers of fine-grained materials drain slowly to the coarse-grained permeable layers which, in turn, feed most of flow to the well. Delayed yield can be documented only after several weeks of continuous pumping and detailed observations.

Where pumping tests have been made in unconsolidated formations for a sufficient length of time to determine the end point of delayed drainage, the ultimate coefficient of storage has been equal to or approached the specific yield for that kind of material. Specific yield is the water drained from a unit volume by gravity drainage. Examination of the porosity of many kinds of fine-grained materials indicate that most have values of 20 to 40 percent; however, when the formation is drained, a large part of the water contained is retained in the pores, so that the specific yield commonly ranges from 1 to 15 percent.

Under the confined conditions occuring in the pumping tests in both the upper and lower aquifers, the average storage coefficient for the upper aquifer was 5.0×10^{-4} and for the lower aquifer 1.7×10^{-4}. The difference is considered insignificant. Considering all of the characteristics of the oil shale formations, many of which are only partially known, it is believed the amount of water drained could range between about 0.001 and 0.05 of the total volume of material in the portion of the formation dewatered.

MINE DEWATERING

In order to operate the in situ-type recovery, the area must be dewatered from about 40 feet above the A Groove to about the base of the L-5 zone, a vertical distance of about 500 feet. While the entire volume above the mining area need not be dewatered, the volume represented by the mining area must be sufficiently dry for work to progress and so that combustion can take place. The mining plan requires that both the lower part of the upper aquifer and the upper part of the lower aquifer be dewatered at the same time, rather than progressively. This dewatering could be accomplished by means of wells or through drainage utilizing the internal development and operational openings in the mine itself. Based on experience in successful mining operations in all types of formations and on the economy of water removal, dewatering by use of the internal mine development is considered best suited for the Cb Tract.

Drainage will be accomplished by conveying the inflow into drifts and rooms to sumps at one or more levels in the mine and pumping the water thus collected out through

shafts to the surface for disposal. For reasons of economy, pumping will probably be from both the air level and from a low level in the mine workings. If it proves desirable or necessary, the pumpage from the two levels could be kept separate for treatment or disposal.

Drainage begins with shaft sinking, intensifies with the first advances in initial development, and reaches a maximum dependent on the time frame for areas open and prepared for retorting. The variation of the rate of drainage with time and area of mine development can be calculated by use of methodology developed by Jacob and Lohman in an investigation of "Nonsteady Flow to a Well of Constant Drawdown in an Extensive Aquifer." Their equation in units used in this report is:

$$Q = 0.0043633\ T\, G\alpha\, s_w$$

where Q = inflow in gallons a minute at end of time period "t"

T = transmissivity in gpd/ft

s_w = depth in feet from initial static water level to level of drainage

$G\alpha$ = an integration of α as tabulated by the authors

$$\alpha = 0.1337\ Tt/r_w^2 S$$

where T = transmissivity as above in gpd/ft

t = time in days since drainage began

r_w = effective radius of mine development at time "t"

S = coefficient of storage

The effective radius of the mine drainage area and its relationship to the radius of the well in the formula needs explanation. In the Jacob-Lohman derivation, the flow enters the well horizontally through the circumference of the bore with no source within the bore. In the mine, the drainage is collected by boundary drifts around the mining activity as well as by the interconnected workings necessary for retort construction inside those drifts.

Although the area enclosed by the boundary drifts may not be circular, the effective radius (r_w) has been taken as that of a circle whose area is equivalent to the

irregular area of mining activity. The drainage computations are based on an effective radius to include an increasing area of development each year according to the production schedule for the mine. The rate of increase is approximately 80 acres annually, reaching a total of about 4620 acres with complete development of the Tract.

The amount of drawdown(s_w) in the calculation, is from altitude 6600 of the present water table to the bottom of the air drift at altitude 5550, or 1050 feet for the upper aquifer. In the lower aquifer it is from altitude 6600 to the bottom of the production drift at altitude 5050, or 1550 feet for the lower aquifer. The foregoing altitudes pertain to but one point within the Tract. The mine workings will generally follow the dip of the formations and the relationships between water levels and depths of dewatering will approximate those used in the computations throughout most of the area to be mined.

Weighted average values of the coefficient of transmissivity in the computations are 1500 and 400 gpd/ft for the upper and lower aquifers respectively. The storage coefficient is assumed to range from 0.001 to 0.05 for both aquifers. Recharge and leakance between aquifers are not accounted for. Recharge is small in amount, and including its effect during the mining period would not significantly modify the drainage estimates. The differential head between the upper aquifer and the lower aquifer and the amount of cross formational leakage through the Mahogany Zone are believed to be inconsequential in dewatering the Cb Tract. In fact, instead of downward flow as may exist prior to pumping, the opposite most probably will occur if both the upper and lower aquifers are dewatered simultaneously.

Figure 10 indicates the profile of the pressure surface or water level in both aquifers while being dewatered. It should be noted that the water level in the upper aquifer is always below that in the lower aquifer where the transmissivity of the upper aquifer has a higher value than that of the lower, and the storage coefficient in both are about the same. For rates of pumping and aquifer coefficients expected for dewatering the Tract, the maximum head differential of the lower aquifer may be about 300 feet over that in the upper aquifer.

Table 3 shows the range in the estimated rates of pumpage and annual volumes of drainage water produced in dewatering the mine throughout the life of the project. The same information is depicted on Figure 11.

Table 3

Estimated Mine Drainage Water Production
(exclusive of water introduced
into mine during construction and operation)

Project Year	Estimated Lower Limit		Estimated Upper Limit	
	gpm	af/yr	gpm	af/yr
(1)	(2)	(3)	(4)	(5)
2	500	800	500	800
4	3400	5500	8,800	14,100
6	3800	6100	9,550	15,400
10	3800	6100	9,850	15,800
20	3900	6300	10,200	16,400
40	4000	6400	10,300	16,600
60	3900	6300	10,350	16,700

The estimated lower and upper limits of groundwater inflow into the mine derive from the use of storage coefficients ranging from 0.001 to 0.05. It is anticipated that actual inflow into the mine may at times approach either of the estimated limits depending on rock structure, fracturing, mining methods,and other factors, but that over the long term the average pumpage required to dewater the mine will fall within the foregoing limits. As each new drift is excavated to unwater new areas,inflow from those areas will reach a peak and then gradually subside. More or less continual expansion of the mine will tend to offset the effect of subsiding flow into areas previously mined and result in an essentially constant inflow following the initial development period, as indicated in Table 3 and on Figure 11. Throughout the entire period of mine dewatering the contribution of water from the upper aquifer is approximately twice that from the lower aquifer.

No effects of any other pumping or mining activity in the Piceance Basin are reflected in the foregoing estimates. Conceivably simultaneous dewatering in another area, as for example, the Ca Tract to the west (Figure 1), might reduce the pumpage required at Cb a modest amount. The U.S.G.S. concluded, however, from its model study that simultaneous dewatering of the two tracts would have little or no effect of one on the other.

Conceivably it would be possible to unwater the mining area with deep wells, but this alternative was discarded for a number of reasons. The specific capacity of wells in the area is generally so low that wells drilled far below the mining zone would be required to drain to the lower levels. This would result in pumpage of the much poorer quality water at depth. Since this water could not be readily accommodated, the lower portion of the mine would have to be internally drained, requiring a duplicate pumping system, albeit of smaller capacity than if it were the primary system.

Furthermore, if dewatering wells were to be located outside the mining area, a higher total discharge would be necessary since the effective radius of dewatering would be greater. Yield of individual wells would decline as dewatering proceeded, requiring continual equipment revision. Near the ultimate dewatering levels, yields would be very low and an excessive number of wells would be required. Although a well dewatering system is not currently planned, situations conceivably could be encountered during mining operations where one or more deep wells might be useful in reducing hydrostatic pressures and concentrated inflows or in removing water of objectionable quality.

Quality of Drainage Water

Data on quality of water which will be encountered in dewatering the Cb Tract are variable and sometimes conflicting. Figure 12 shows the total dissolved solids from wells perforated in the intervals shown; Figure 13 shows fluoride analyses for the same intervals. The mining zone is shown for altitude information only.

Electrical conductivity measurements made on return water while drilling indicate a general pattern of relatively high dissolved solids, 1000-1500 ppm, just below the water table, underlain by relatively low values (700-800 ppm) through the Mahogany Zone, then high concentrations ($>$ 2000 ppm) at levels below the mining zone. This pattern appears to be borne out by samples from cased wells also. Six wells which are perforated in the 150 foot section above the Mahogany Zone average about 740 ppm, while eight wells obtaining water from more than 150 feet above the Mahogany Zone average 1354 ppm.

Within the Mahogany Zone, four wells average about 750 ppm and one well is at about 2600 ppm. In this latter case, however, it is believed that contamination from below is involved. At about 400-500 feet below the mining zone, some wells have encountered highly mineralized water.

Two wells are particularly anomalous, SG-19 and SG-20. Both are open only to the upper aquifer, but yield water which is typical lower aquifer water, high in sodium bicarbonate and fluoride. Generally, however, the chemistry of groundwater differs quite strongly above and below the Mahogany Zone.

With regard to fluoride, the evidence is also conflicting. Samples from wells sampling the Mahogany Zone and above range from 0.4 ppm to 22 ppm. The deeper samples are consistently above 15 ppm. In the aquifer test at AT-1, upper aquifer water increased from about 3 ppm to 18 ppm fluoride in 23 days of pumping, while the original TDS (760) reduced somewhat. In the lower aquifer in the same well, both fluoride (19 ppm) and TDS (750 ppm) remained about constant.

While some of the horizons under the mining zone are very high in dissolved boron, it is believed that this element will not be a great problem. The aquifer test on AT-1 reached 1.5 ppm boron in the upper aquifer and 3 ppm in the lower, but most upper aquifer analyses show less than 1 ppm except where leakage probably occurred.

A number of factors can affect the data on which a judgement of final water quality must be based. It appears there are some incorrect analyses; sampling methods differ; leakage through unsealed boreholes has definitely occurred; and there is obviously an actual variation in quality over the Tract. Even if all data are correct, however, a weighted average of the test results would not necessarily represent the composite quality of the drainage water. It is likely that the more permeable zones from which the higher flows of water will be derived will also yield the better quality water. Therefore, it is to be expected that the poorer quality water will be diluted to some extent. The anisotropy of the upper aquifer will probably result in lower vertical drainage velocity than the horizontal velocity at and around the mining zone, resulting in the high TDS water at the water table also being diluted. It is possible that all of the upper zone will not be dewatered during the life of the project.

Little vertical (upward) leakage is expected, which might bring highly mineralized water into the mine. If high pressures are found which might result in upward leakage, it might be necessary to drill relief wells and to handle that water separately.

The quality of water pumped from the mine is expected to vary from time to time and from place to place. For planning purposes, the following values have been adopted:

	Total Dissolved Solids (ppm)	Fluoride (ppm)	Boron (ppm)
Upper Aquifer	950	10	1.2
Lower Aquifer	1100	20	2.5
Mixed 2 to 1	1000	13	1.6

The actual quality of water pumped from the mine may be somewhat better than the foregoing values but it is doubtful whether better estimates can be made until after mining and dewatering operations have been undertaken.

EFFECTS OF MINE DEWATERING

The dewatering of the mine will create a cone of depression around the mine within which the piezometric level will be lowered. The size of the cone, i.e., the area over which the piezometric level will be lowered, will increase as long as pumping continues. It will continue to increase for a period of time following cessation of pumping and then gradually recover as recharge fills the unwatered area.

Where groundwater reaches the stream through springs and seeps that are supplied from the upper aquifer, the lowering of the piezometric level may reduce the amount of groundwater discharge and hence streamflow in those areas. The lowering of the piezometric level in the lower aquifer at the Cb Tract will have a negligible effect on streamflow although it may improve downstream quality by reducing upward leakage from deeper saline aquifers. For the purpose of this analysis, the assumption is made that groundwater discharge to streams from the upper aquifer might begin to show a reduction in flow when the piezometric level is lowered more than about one foot. This reduction in head is much less than the seasonal fluctuations in water levels in some wells and observation holes.

The radii of the cone of depression to a contour representing a one-foot reduction in piezometric level for various time periods are shown below.

Project Year	Radius from Center of Mine (miles)
5	-
10	2.2
20	3.8
30	4.9
40	5.8
50	6.6
60	7.2

The foregoing values are based on the high estimate of discharge in the dewatering operation.

On Figure 14 the dewatered mine is portrayed as a hatched circle of equivalent area within Cb Tract. The concentric contours depict the areal extent of a one-foot reduction in piezometric level in the upper aquifer for increasing time periods.

Because of the general dip of the formations and the corresponding aquifers, these contours would not be truly circular, but their departure therefrom would be relatively insignificant. It may be noted that the 30 year contour encompasses approximately 10 miles of Piceance Creek north of the Tract. This is roughly the same length of stream the U.S.G.S. determined would be affected by mine dewatering for that period of time. Nearly 15 miles of Piceance Creek lie within the 60 year contour.

Within the areas shown on Figure 14 pumpage may affect groundwater discharge and water levels in wells. While the effect on individual wells in the upper aquifer can be predicted, the reaction of individual springs, alluvial wells, and various reaches of surface streams will range from no effect to total depletion. Surface runoff and groundwater discharge from perched aquifers will not be significantly affected.

Those reaches of streams within the Piceance Creek watershed that lie below the groundwater piezometric levels are shown in blue on Figure 14. Natural piezometric levels are taken as those determined by the U.S.G.S. to represent composite heads in the upper and lower aquifers under predevelopment conditions. While not strictly correct, it is assumed for this analysis that most of the groundwater discharge forming the base flow component of stream flow originates in the stream reaches shown in blue on Figure 14. Excluding the reach along the Dry Fork of Piceance Creek (which contributes little to the base flow) a total of approximately 86 stream miles in this category lie within the Piceance Creek watershed. Within the zone of the cone of depression, corresponding to the 60-year projected life of the mine, there are approximately 43 stream miles having their beds below present piezometric levels. Accordingly it is estimated that at that stage of development groundwater discharge to the stream may be approximately one-half of that which presently occurs.

The reduction in piezometric levels attributable to mine dewatering will also reduce the amount of water consumed by native vegetation in high water table areas, resulting in a net "salvage" of water. Incorporating these adjustments in the water production estimates shown in Table 1 on page 13 yields the values indicated in the following Table.

Table 4

Estimated Annual Water Production and Runoff of Piceance Creek Basin after 60 years of Mine Dewatering (all values in acre-feet)

	Year of Subnormal Runoff	Year of Average Runoff	Year of Above Normal Runoff
Water Production:			
Base flow component	5,000	7,000	9,500
Seasonal flow component	7,000	10,000	14,000
Total	12,000	17,000	23,500
Water Consumption:			
By native vegetation	2,000	2,000	3,000
By irrigated crops	5,000	6,000	7,000
Total	7,000	8,000	10,000
Net Basin Outflow	5,000	9,000	13,500
Deficiency attributable to mine dewatering	3,000	4,000	6,500

The bottom line in the foregoing table represents the estimated reduction in basin runoff attributable to dewatering a mine on the Cb Tract. It represents the annual volume of water required to be supplied to the stream in order to maintain surface flows at their pre-mining levels, ranging from a minimum of 3,000 to a maximum of 6,500 acre-feet per year with an average annual augmentation requirement of 4,000 acre-feet. These values pertain to conditions expected to prevail when the ultimate mine is fully developed. Similar accounting of stream flow reaches affected by the cone of depression indicates a near linear increase in streamflow depletion from nil in year five to the full amount in the 60th year of operations.

The preceding analysis does not separately identify incremental streamflow losses across the cone of depression created by mine dewatering. Such losses, however, are believed to be small and more than compensated for in the estimates of reduction in groundwater discharge. It has been observed that surface streams in the area are not in complete communication with the upper aquifer. There are reaches in which induced leakage into the

aquifer will be extremely low. In other reaches, where the stream flows on permeable alluvium which is in communication with the upper aquifer, leakage will be limited by the permeability of the stream bed and the available head. Roan Creek, on the south side of the Piceance Basin, is perched well above the water table throughout much of its length and shows no evidence of excessive leakage.

As noted earlier, four pairs of alluvial and upper aquifer wells on and near the Cb Tract for which data are available indicate no similarity of water levels or fluctuations which would be expected if there were complete direct communication with the upper aquifer. Further, during drilling of core hole 33X-1 at the mine site, rapid and significant drawdown was observed in SG-19 and SG-20 which are located in the flood plain of Piceance Creek. If the Creek were a constant head source in the vicinity of those wells, little or no effect should have been observed. No effect was observed on springs in the area nor was any drawdown noted in alluvial wells during operations which produced drawdowns in SG-19 and SG-20. The assumptions that groundwater discharge from the upper aquifer to streams occurs only in the reaches indicated on Figure 14 and that all of such discharge will cease within the cone of groundwater depression is believed to adequately account for any incremental channel losses that may occur.

After Cessation of Mining

During the projected 60-year life of the project a total volume of groundwater, in the range of 350,000 to 850,000 acre-feet, will have been removed in the mine dewatering operations. In order to completely restore the original hydraulic regime in the area of the Tract, this volume of water plus the volume of rock removed from the mine would have to be replaced, either by natural recharge, by artificial means, or a combination of the two. Several hundreds of years might be required to replace this water by natural means. At the moment the dewatering pumps are shut down upon cessation of mining, water will be flowing into the mine at the same rate at which it was being removed immediately prior thereto. Most of that inflow will continue to be supplied from storage in the aquifer and cause the unwatered area to continue to expand. Full recovery, if dependent solely on natural recharge might take an inordinately long period of time, particularly since when the groundwater level reaches stream levels the component of natural recharge entering the dewatered area would be still further reduced.

To attempt to estimate the time required for recovery by natural means would be a purposeless exercise for a number of reasons. Assuming that recovery of oil from oil shale proves to be economically feasible, it is certain that development of this resource will not cease upon termination of mining on the Cb and Ca Tracts. Assuredly the demand for petroleum products 60 years hence will be many times more critical than at present, and new mines requiring a similar degree of dewatering will be developed adjacent to or in the vicinity of the Tracts currently under Federal lease. Groundwater developed in dewatering new areas that is not utilized on the site or to replace streamflow depletions would logically be introduced into previously mined areas. Should such other new developments never take place, the works that would have been provided to import water from another source for augmentation of streamflow, such as the White River, would conceivably either be enlarged, or be utilized to a greater degree, in order to replenish groundwater removed and shorten the time the Lessees might be obligated to augment the streamflow. Conceivably by these measures the period required to restore groundwater levels on the Tract could be reduced to 25 to 40 years.

WATER MANAGEMENT

As shown on Figure 11, within a few years after initiation of operations on Cb Tract, the rate of groundwater inflow into the mine will reach a level of 4,000 to 10,000 gallons per minute (6,400 to 16,000 acre-feet per year) and remain at these rates of flow for a period of nearly 60 years. A portion of this mine drainage water will be consumptively used in other operations, most of which will be at the surface of the Tract, and are referred to herein as "on-site water uses". A portion of the mine drainage water will be utilized to replace depletions in the flow of Piceance Creek and some of its tributaries attributable to the dewatering operations. This use is referred to herein as streamflow augmentation. The amount of water required for this purpose will increase as mining proceeds and will continue for an extended period of time after all mining has ceased 60 years hence. In addition, depending on the time frame and the actual amount of water produced in dewatering the mine, there will remain varying amounts of surplus water to be disposed of.

Several kinds of physical works will be required that are common to any plan of use and disposal of water pumped from the mine. These will comprise facilities for the sedimentation of suspended solids contained in water pumped from the mine, filtration facilities, works to reduce the concentration of fluoride and possibly also boron contained in water pumped from the mine. Depending on its ultimate use, a portion of the mine water will be treated to reduce its dissolved salt concentration. In addition to the foregoing works, a storage reservoir having a capacity of approximately 4,000 to 5,000 acre-feet, situated on or in the vicinity of the Tract, will be required to regulate the essentially constant rate of mine discharge to varying demands of the various uses and to provide the necessary flexibility and reserve supply for the overall water operations. This feature is referred to herein as the "regulatory reservoir'. In addition to the foregoing basic features, there will, of course, be many other kinds of works required for handling of water in the shale oil processing operations and the supplying of water for human consumption and for other uses associated with those operations.

On-Site Water Uses

On-site water uses can be considered to fall into two categories: (1) those uses which involve only the mine drainage water consumed on the site; and (2) those uses involved in the production and processing of oil shale. Parsons' studies of water uses in the second category indicate that insofar as water is concerned, the production and processing operations are self-sustaining; and except during the first few years of development, those operations place no demand on either surface or groundwater supplies. Actually when commercial production is reached, a small amount of water is produced in the processing operations. Although relatively large quantities of water, principally in the form of stack losses, are consumed in those operations, most of such water is generated in the retorting operation and in the burning of hydrocarbons. For these reasons, the discussion which follows is concerned only with the use and disposal of groundwater produced in mine dewatering operations.

Consumptive uses of mine drainage water on the Cb Tract are estimated to be equivalent to 1,250 gallons per minute (2,000 acre-feet per year) made up of the following items:

Table 5

On Site Water Uses

Water Use (or Loss)	Gallons per Minute
Ventilation exhaust (net loss)	130
Mine muck	50
Construction use, dust control, etc.	300
Shale disposal and revegetation	750
Potable water (less return)	20
	1250

According to flow sheets prepared by Parsons, when commercial production is reached a net water surplus, equivalent to about 240 gpm, will be produced, thus reducing the demand on mine drainage water to about 1,000 gallons per minute. This projected water surplus from processing operations, however, is ignored herein in order to allow for unforeseen increases in the use of drainage water on the site.

The uses indicated in Table 5 represent average annual rates of use, most of which will be a little higher than the values indicated in the summer and a little less during the winter. Such seasonal variations in use can be readily accommodated by the regulatory reservoir. On-site uses of drainage water will be essentially constant throughout the life of the mine. While during the initial development period uses may be somewhat less than those indicated on Table 5, the reduction in use will be offset by a small amount of mine drainage water used for boiler feed-water until the commercial level of operations are attained.

Streamflow Augmentation

As discussed in an earlier section, dewatering of the mine will lower groundwater levels in the vicinity of the mine and hence may cause a depletion of streamflow if the water pumped from the mine is not returned to the stream. If all of the mine drainage water were to be discharged directly into the streams surrounding the mine, streamflows would be increased over what they would otherwise have been by the amount of water removed from storage in the aquifers. This increase in streamflow would be a temporary phenomenon, however, as upon cessation of mining the hydrologic system would have an accumulated deficit equivalent to the volume of groundwater removed from aquifer storage. Furthermore, during the life of the project, a portion of the water pumped from the mine will be consumptively used as discussed above. This in effect would amount to the taking of water that is junior in priority to other vested water rights in the basin. Colorado Water Law recognizes the right of a junior appropriator to initiate and establish a new beneficial use of water so long as measures are taken to replace the water so used in a manner such that senior rights within the basin are not adversely affected. The means to accomplish this objective is commonly referred to as a "Plan for Augmentation". The streamflow augmentation plan must be submitted to, and be approved by, the Water Court before any actions which might affect the flow of the stream are undertaken or new uses of water are made.

As discussed under the section on the effects of mine dewatering, it is estimated that by the time the Cb Tract has been fully developed, the average annual depletion in streamflow attributable to dewatering of the mine will be in the order of 4,000 acre-feet

annually, varying from about 3,000 acre-feet in a year of subnormal runoff up to 6,500 acre-feet in a year of above normal runoff. These volumes correspond to the estimated depletions in streamflow near the end of the mining period. The first five years of dewatering operations will have very little effect on streamflow. As mining continues, however, increasing amounts of water, up to the limits cited above, will be required for streamflow augmentation.

At any particular point in time, water will be discharged from the mine at a relatively constant rate of flow. As it is primarily the base flow of the stream that will be affected by dewatering operations, it follows that water introduced into the stream to replace depletions would also logically be at a more or less constant rate throughout the year. It will be recalled, however, that in estimating the replacement requirement, credit was taken for the reduced consumption of water by native vegetation in areas of lowered groundwater levels. The water salvaged in this manner will accrue to the system during the summer months. Thus, if augmentation water is discharged to the stream at a constant rate of flow, it would have the effect of increasing supplies over what they otherwise naturally would have been during the summer and reducing them slightly during the winter. Such an operation, nevertheless, will be beneficial in the Piceance Basin where streamflow is utilized primarily for irrigation during the summer months.

In the case of the Cb Tract, the plan for streamflow augmentation will necessarily comprise at least two means of satisfying the requirement of protecting existing rights during the life of the project and beyond during the period of time required for the hydrologic system to recover from the effects of mine dewatering. These water augmentation operations can be considered to fall into two phases, defined as follows:

Phase I — <u>Will utilize mine drainage water</u> to augment the streamflow — so long as the unused mine drainage water (total drainage less on-site use) is adequate in amount to supply the augmentation requirement, it will be treated as required and discharged directly into Piceance Creek at appropriate points. On the basis of the estimates of streamflow depletion described herein,

this method of streamflow augmentation will probably suffice throughout the projected 60-year life of the mine.

Phase II — Will utilize imported water to augment the streamflow and to replace groundwater withdrawn from storage — at such time as the unused mine water is inadequate in amount to supply on-site uses plus streamflow augmentation requirements, the deficiency will be supplied by water conveyed from the White River to the Tract and/or appropriate points on Piceance Creek. This source will be utilized following cessation of mining to replace groundwater withdrawn from storage in the dewatering operations. It would continue in operation until the hydrologic system had been restored to near its original condition and augmentation of the stream is no longer required.

The foregoing operations pertain to augmenting streamflow in a manner such that vested rights for diversion of water from Piceance Creek and its tributaries are not adversely affected. Dewatering operations may affect certain off-stream wells in the area, and arrangements would be made with the owners of such rights to either supply them with water to the extent they are affected or to compensate them for the cost of deepening wells or for increased pumping costs.

Under Phase I Operations, wherein mine drainage water is utilized for augmenting streamflow, a pipeline would be provided, extending from the plant site up the valley of Piceance Creek to the uppermost point where augmentation is required. The capacity of this pipeline would be determined on the basis of the amount of water required to be delivered to the stream at that point (tentatively estimated to be approximately 60 percent of the total augmentation requirement). The balance of the water required for streamflow augmentation would be delivered directly into Willow Creek on the west side of the Tract from whence it would flow into Piceance Creek.

The production of drainage water from mine dewatering operations can only be estimated within rather wide limits at present. If the actual water production approaches

the lower estimates contained herein, it might be necessary to import modest amounts of water from the White River prior to cessation of mining, perhaps as early as project year 40 or 50. The water importation works would definitely have to be in operation by the time mining has terminated and dewatering is no longer required.

The Lessees are acquiring the following conditional water rights on the White River, having appropriation dates of August 5, 1966:

> A direct flow right out of the White River in the amount of 100 cfs for the White River-Piceance Creek Pipeline, and
>
> A storage right on the White River in the amount of 75,970 acre-feet for the Powell Park Reservoir.

Both of the above rights are situated on the White River about 8 miles downstream from the town of Meeker. Their decreed uses are for industrial, domestic, irrigation, and related purposes.

Prior to the time it becomes necessary to undertake Phase II augmentation operations, diversion works and a pumping plant would be provided on the White River with a pipeline extending from the pumping plant to the upper reaches of Piceance Creek or to the regulatory reservoir on, or in the vicinity of, Cb Tract. In the latter case, White River water would be delivered from the regulatory reservoir to Piceance Creek through the same works provided for discharge of the mine drainage water. It is tentatively contemplated that the pumping plant and pipeline would have an initial capacity of about 20 cubic feet per second. During the period the mine is in operation, the importation facilities would be utilized only to the extent that mine drainage water is insufficient for augmentation requirements. The pipeline right might be utilized for only a few months during the flood season with such regulation as is required being afforded by the regulating reservoir.

Upon cessation of mining, the water importation works would be utilized to the maximum extent water is available under the mentioned rights. Water imported from the White River in excess of that required for streamflow augmentation would be delivered

into the mine workings in order to restore groundwater levels in the dewatered zone and to shorten the period of time during which augmentation is required. To make year-round use of the facilities for conveying water from the White River to the Tract, additional reservoir storage may be required to capture water during years of above-normal runoff for use during periods when water is not available under the direct flow pipeline right. Should this prove to be necessary, the Powell Park Reservoir on the White River would be provided. If, as expected, dewatering operations at other mine sites within the Piceance Basin are underway at that time, surplus drainage water from those operations might be utilized in lieu of the White River source of supply.

Surplus Mine Drainage Water

Figure 15 shows the estimated lower and upper limits of water that will be pumped from the mine during the life of the project and the anticipated amounts thereof that will be used on the site and for streamflow augmentation. The hatched area on this chart represents the quantity of mine drainage water that will be surplus to those requirements. With the lower estimate of mine drainage, this surplus ranges from about 4,000 acre-feet per year during the early years of development to near zero surplus at the end of the mining period. With the higher estimate of mine drainage, it ranges from 14,000 acre-feet per year down to about 10,000 acre-feet per year at the time mining ceases.

The uses for, or methods of disposing of, this surplus mine drainage water have not yet been decided. Among the options for use or disposal of this water are the following:

a. New or increased "on-site" uses.

b. New "off-site" uses.

c. Discharge to Piceance Creek.

d. Re-injection in groundwater aquifers.

On-site consumptive uses of water could be enlarged somewhat during the summer by applying irrigation water to areas other than the raw shale disposal areas to be re-vegetated. These might include previously "chained" areas or other topographically

suitable zones on the Tract where irrigation by sprinklers would not produce undesirable erosion. The pressure pipe system for summer irrigation could be adopted for snowmaking during the winter at selected sites within the Tract and thereby enhance surface runoff during the following spring. The incremental consumptive uses of water that might be obtained by these practices probably would not exceed over 2,000 acre-feet per year and care would have to be taken to ensure that the ecosystem is not so drastically altered that it would not be self sustaining in the absence of artificial irrigation.

Depending on the amount and firmness of the supply, surplus mine drainage water affords the opportunity of on-site generation of thermal electric energy, utilizing off-gas from retorting operations as a fuel, if such proves to be technically and economically feasible.

Off-site uses of surplus mine drainage water could conceivably be developed. It could be delivered, or made available, to another oil shale development in an area where water would otherwise have to be imported, as for example, along the southern flank of the Roan Plateau; or surplus drainage water could be utilized for irrigation of arable lands in other areas of the basin. This could be done either by direct command, utilizing a pipeline or other conveyance works, or by exchange for streamflow in another part of the White River Basin providing a suitable exchange potential exists.

Discharge of surplus mine drainage water to surface streams could be made providing its quality meets the requirements of the discharge permits that would be required. Water discharged directly into Piceance Creek would have to meet the same quality requirements as water utilized for streamflow augmentation as discussed in the following section.

Re-injection of surplus mine drainage water into an aquifer or aquifers would have the advantages of reducing the effect of mine dewatering on springs and streamflow and require little or no treatment to make its quality compatible with that of the receiving aquifer. On the other hand, depending on the locations at which water is injected, the amount of mine pumpage could be increased owing to recirculation. In

order to limit the amount of re-injected water which is recirculated through the mine, the injection loci should be situated as far as possible from the mine, well off the Cb Tract. Depending on the total quantity of water injected and the horizon in which it is placed, a relatively large number of individual wells would be required. These would have to be widely spaced to avoid excessive interference which would require that many miles of buried pipeline would have to be constructed to deliver water to the individual wells. Maintenance of injection capacity would be difficult and standby wells and facilities would be necessary. If water were to be injected into the lower aquifer, leakage of highly saline water through fracture springs might be increased and thus further degrade the quality of streamflow in the lower reaches of Piceance Creek. While re-injection cannot be ruled out as a means of temporarily disposing of small quantities of surplus water on an interim or short-term basis, it does not presently appear to be an attractive method of disposing of large volumes of water for a sustained period.

All of the foregoing options which involve the use of mine water for irrigation, or discharge to surface streams, or other uses which would result in part of the water returning to surface streams, will probably require some degree of quality control. Furthermore, the surplus drainage water does not represent a permanent source of supply, but one that would be available only during the period of mine dewatering.

Selection of feasible combinations of options for the use and/or disposal of surplus mine drainage water will be dependent on the amount of water involved, environmental factors, and economics. It is likely that the amount of drainage water that is surplus to other requirements will not be known with sufficient accuracy to intelligently evaluate all of the factors involved until after several years of experience have been gained at the planned level of commercial operations. Certainly, firm commitments for the delivery of fixed quantities of water, and large investments in conveyance facilities or other works could not be made until the range in present estimates of surplus water can be narrowed. Until that time, the most logical option for disposal of surplus water will be direct discharge into Piceance Creek. This in turn will necessitate the same degree of quality control as required for augmentation of streamflow as discussed in the following section.

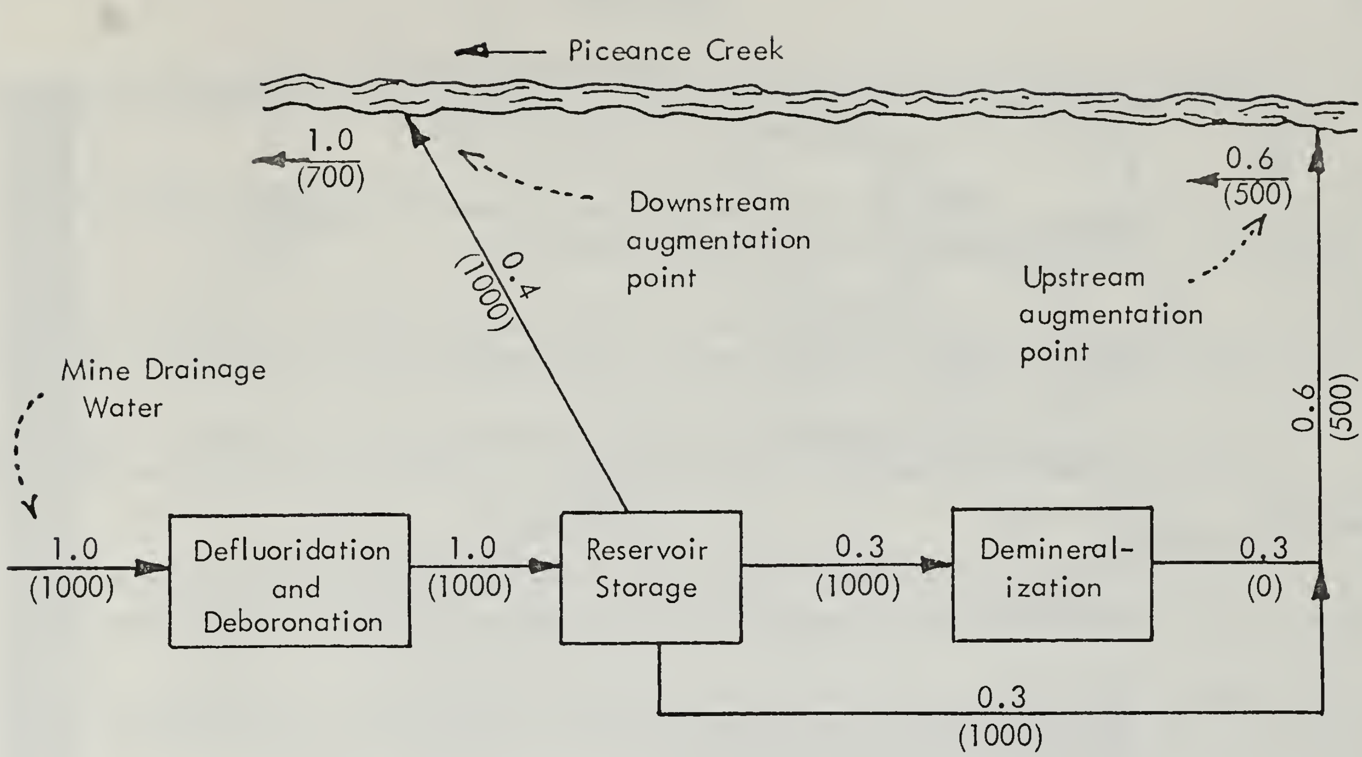
Water Quality Control

Mine drainage water that is utilized for most of the projected on-site uses, including revegetation of raw shale disposal areas as well as that used for augmentation of streamflow, will have to be processed and treated to produce water of a quality comparable to that of surface streams in the vicinity of Cb Tract. The same requirements will apply to surplus drainage water that is discharged to Piceance Creek or utilized for other uses on the Tract which might result in runoff or percolation reaching surrounding streams. These requirements in turn will make it necessary to remove excessive concentrations of fluoride and boron from the mine drainage water and to reduce its total dissolved solids content.

According to plans developed by Parsons, all of the mine drainage water will be settled and filtered to remove suspended solids and be defluoridated and deboronated to the extent necessary to meet standards of the Colorado Department of Health for water for agricultural and domestic use. Demineralization will be accomplished using a dual bed, cationic/anionic resin ion exchange system. Only part of the dissolved solids must be removed and, therefore, only a portion of the mine drainage water will be treated, with the remainder bypassing the demineralizer to join the effluent stream.

A target content of 700 ppm dissolved solids in the water destined for the foregoing uses has been adopted. This concentration is below the average dissolved solids content of normal streamflows in the vicinity of the mine and well below the dissolved solids content of natural springs and seeps which flow into Piceance Creek in the vicinity of Cb Tract.

The pipeline required for streamflow augmentation purposes, extending up the valley of Piceance Creek to the east of the Tract, will afford an opportunity to control the quality of water discharged to the stream in a manner that will approximate natural changes in quality in this reach. This is illustrated by the schematic diagram below, in which flow values are represented by decimal parts assuming mine discharge is 1.0, and the corresponding TDS values in parts per million are indicated in parentheses.



It can be seen that the foregoing mode of quality control will allow the discharge of 500 ppm TDS water to the stream at points upstream of the Tract, which when mixed with water released farther downstream (Willow Creek) will not exceed the 700 parts per million standard for total discharge to the stream.

Referring to Figure 8, it may be noted that downstream of the Cb Tract the quality of water in Piceance Creek deteriorates markedly. To the extent that surplus water over and above that required for streamflow augmentation is discharged to the stream, the quality of water in Piceance Creek will be improved over that which exists naturally, particularly in the lower reaches of the stream.

References

Cb Shale Oil Venture, 1976, Oil Shale Tract Cb, detailed development plan and related materials: Report submitted to Oil Shale Supervisor.

____________, 1977, Oil Shale Tract Cb, modifications to detailed development plan: Report submitted to Area Oil Shale Supervisor.

____________, 1976, Oil Shale Tract Cb, first year environmental baseline program, annual summary and trends report: Report submitted to Area Oil Shale Supervisor.

____________, 1977, Oil Shale Tract Cb, environmental baseline program, November '74-October '76, final report, hydrology, Vol. 2: Report submitted to Area Oil Shale Supervisor.

____________, 1975-76, Oil Shale Tract Cb, environmental and exploration program, Summary Reports 1 through 8: Reports submitted to Area Oil Shale Supervisor.

Coffin, D.L. et al, 1971, Geohydrology of the Piceance Creek structural basin between the White and Colorado Rivers, northwestern Colorado: U.S. Geological Survey Hydrol. Inv. Atlas HA-370.

Energy Consulting Associates, 1976-77, Various reports prepared for Cb Shale Oil Venture.

Ficke, J.F. et al, 1974, Hydrologic data from the Piceance basin, Colorado: Colorado Water Conserv. Board, Water Resources Basic-Data Release 31.

Jacob, C.E., and Lohman, S.W., 1952, Nonsteady Flow to a Well of Constant Drawdown in an Extensive Aquifer: Trans. American Geophysical Union, Vol. 33, No. 4.

Murray, D. Keith, ed., 1974, Guidebook to the energy resources of the Piceance Creek basin Colorado: Rocky Mountain Assoc. of Geol.

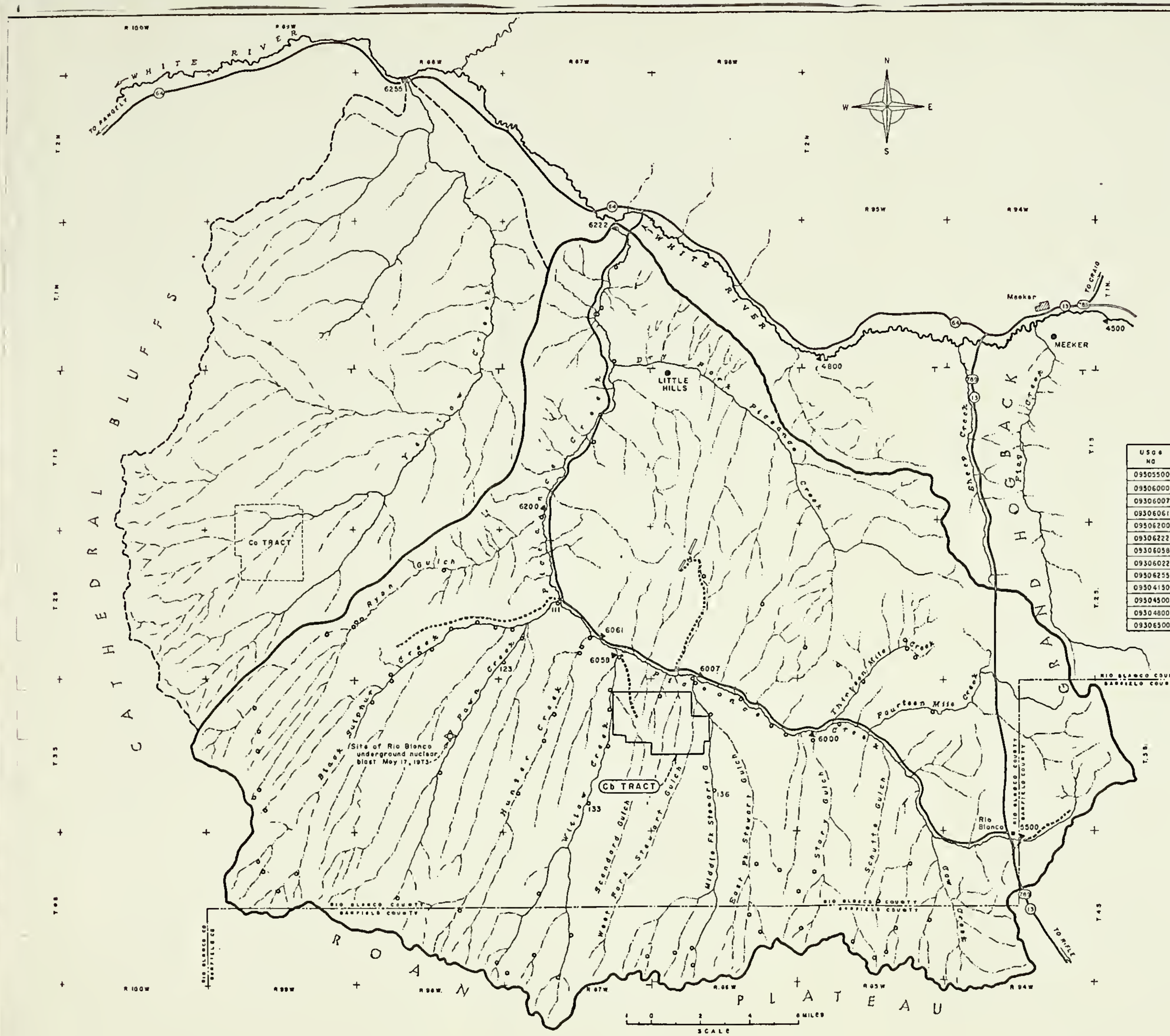
The Ralph M. Parsons Company, 1977, Water management plan: Draft prepared for Cb Shale Oil Venture.

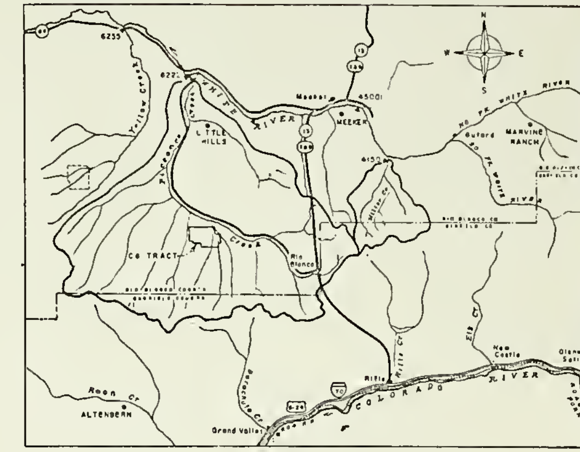
U.S. Geological Survey, 1961-76, Water resources data for Colorado - Part I. Surface water records. 1964-76, Water resources data for Colorado - Part II. Water quality records.

Weeks, John B. et al, 1974, Simulated effects of oil shale development on hydrology, Piceance Basin, Colorado: U.S. Geol. Survey Prof. Paper 908.

Weeks, J.B., and Welder, F.A., 1974, Hydrologic and geophysical data from the Piceance Basin, Colorado: Colorado Water Conserv. Board, Water Resources Basic-Data Release No. 35.

Wymore, I.F., 1974, Estimated average annual water balance for Piceance and Yellow Creek watersheds: Colorado State University Environmental Resources Center, Tech. Report No. 2.





INDEX MAP

KEY STREAM GAGING STATIONS

USGS NO	STREAM	LOCATION	DRAINAGE AREA (SQ MI)	ELEVATION (FT.)	EARLIEST YEAR OF RECORD
09305500	Piceance Creek	At Rio Blanco	9	7,200	1954*
09306000	" "	Near Rio Blanco	153	6,850	1941**
09306007	" "	Below Rio Blanco	177	6,366	1974
09306061	" "	Above Hunter Cr.	509	6,214	1974
09306200	" "	Below Ryan Gulch	485	6,070	1964
09306222	" "	At White River	650	5,705	1964
09306058	Willow Creek	Near Rio Blanco	487	6,273	1974
09306022	Stewart Gulch	Above West Fork	594	6,392	1973
09306255	Yellow Creek	Near White River	262	5,535	1972
09304150	Miller Creek	Near Meeker	576	6,710	1970
09304500	White River	Near Meeker	762	6,320	1901
09304800	" "	Below Meeker	1,040	5,928	1961
09306500	" "	Above Rangely	2,790	5,270	1972

* Oct 1954-Sept 1957 ** Mar. 1941 - Sept 1943

PRECIPITATION STATIONS

STATION	ELEVATION (FT.)	EARLIEST YEAR OF RECORD
Little Hills	6,140	1946
Altenbern	5,690	1947
Meeker	6,242	1969
Marvine Ranch	7,800	1972
Rangely	3,216	1940
Grand Junction	4,855	1891

LEGEND

Drainage basin boundary

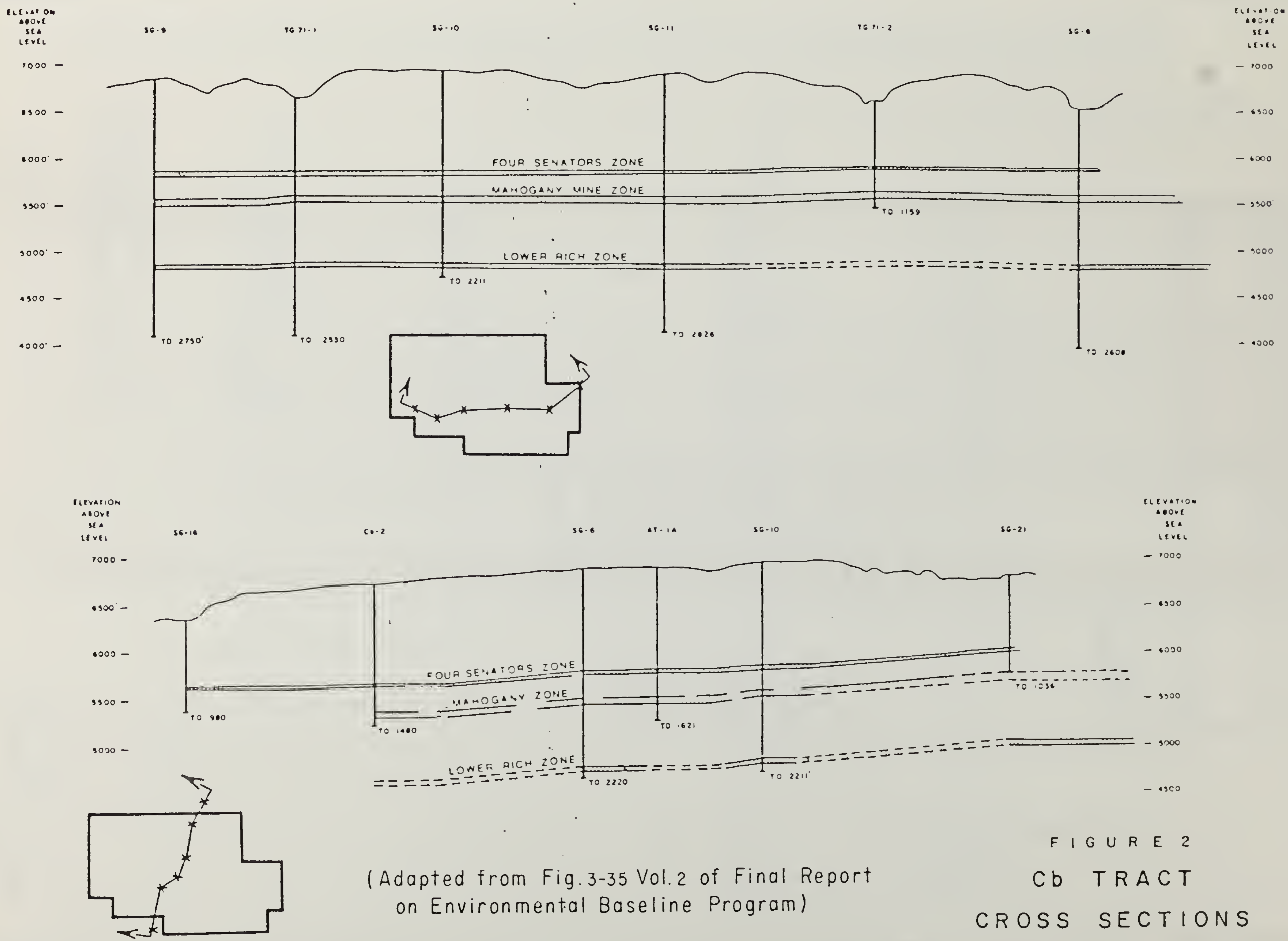
Stream gaging station

Precipitation station

Springs (Numbers refer to CDWR stations)

FIGURE 1

PICEANCE CREEK BASIN

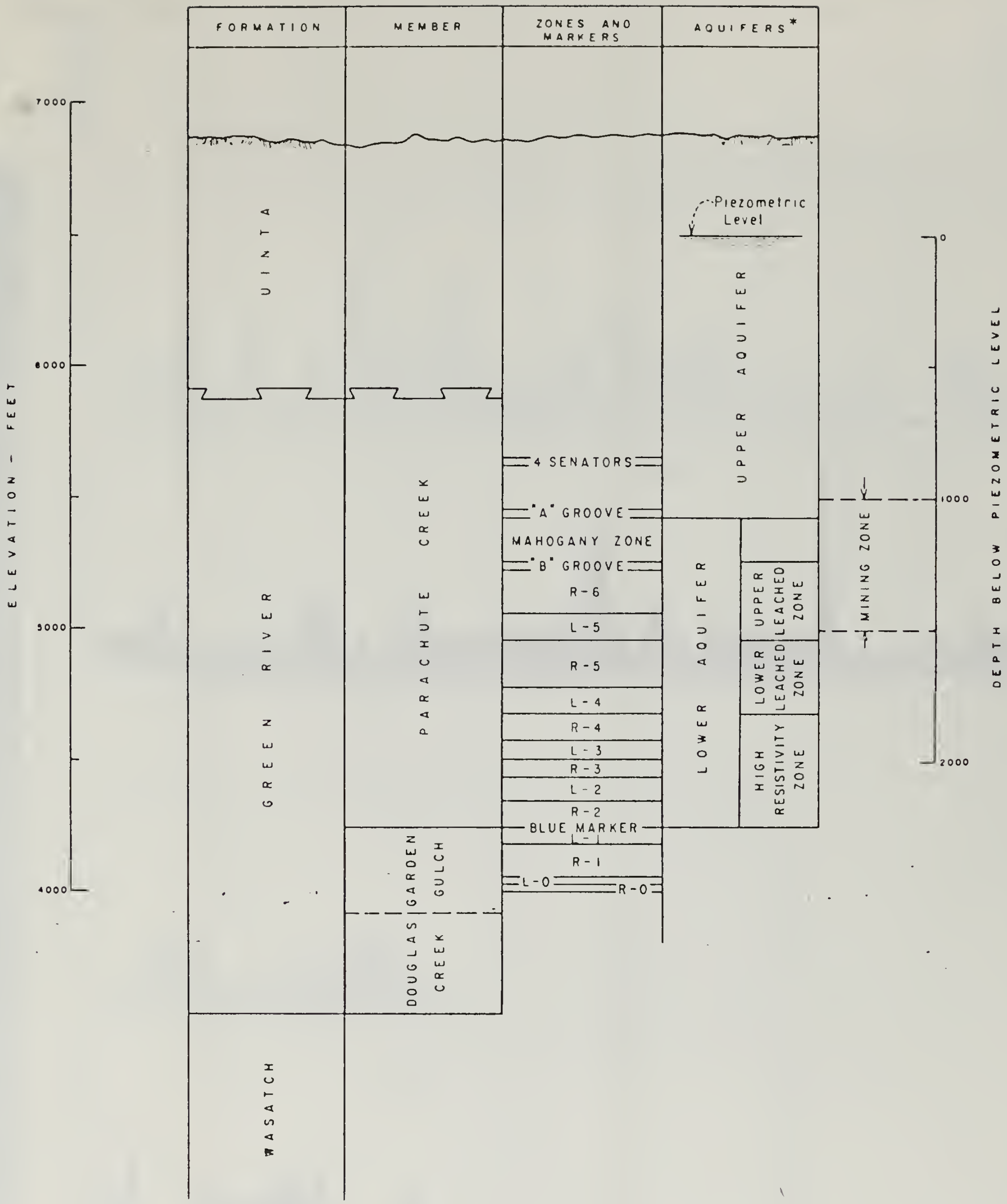


(Adapted from Fig. 3-35 Vol. 2 of Final Report on Environmental Baseline Program)

FIGURE 2

Cb TRACT

CROSS SECTIONS



NOTES

All elevations and depths are generalized and approximate

*: Aquifer designations used in this Report and depths used in dewatering computations

FIGURE 3

Cb TRACT
STRATIGRAPHIC COLUMN

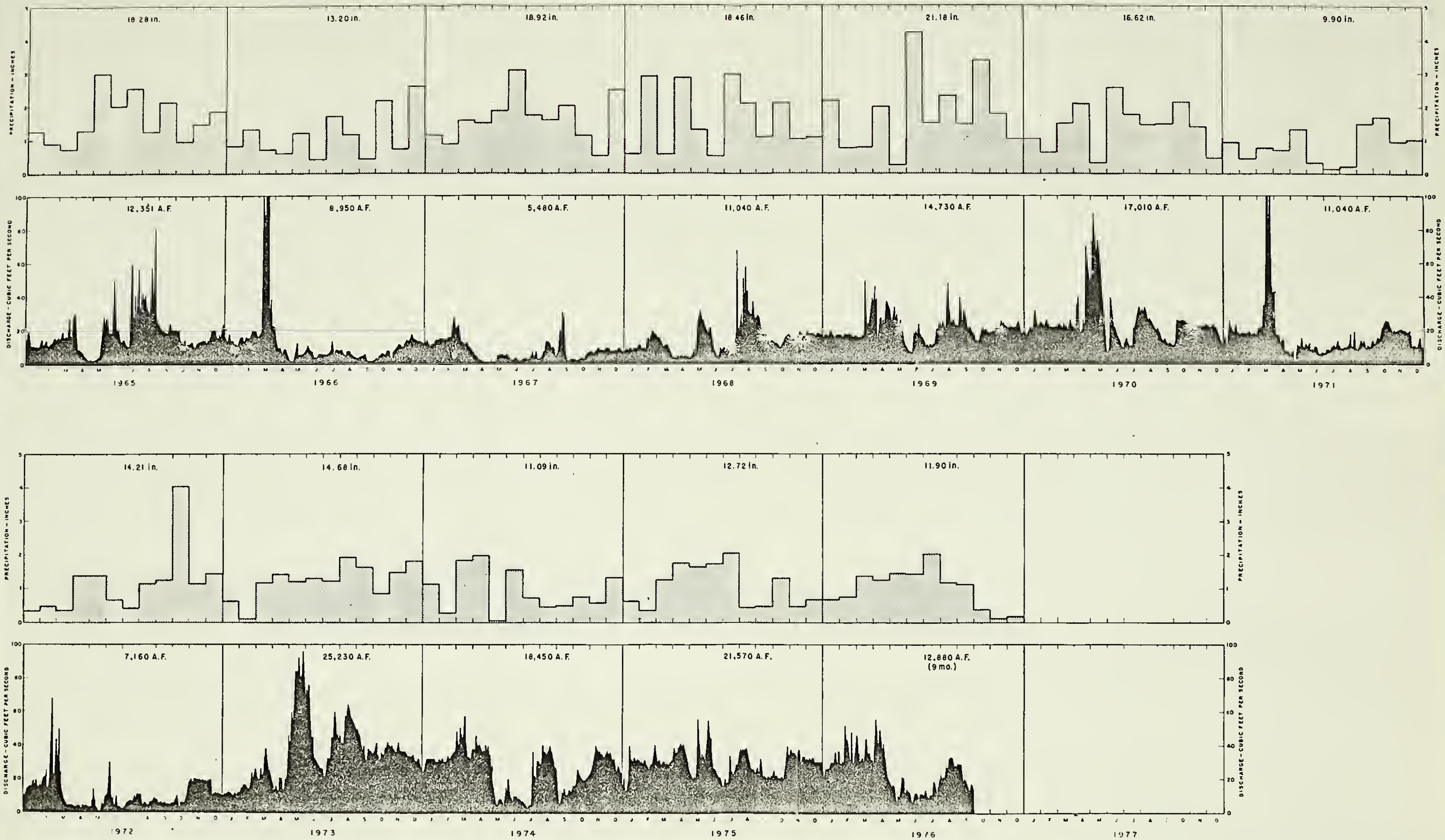


FIGURE 4

FLOW OF PICEANCE CREEK
BELOW RYAN GULCH (09306200)
AND
PRECIPITATION AT MEEKER

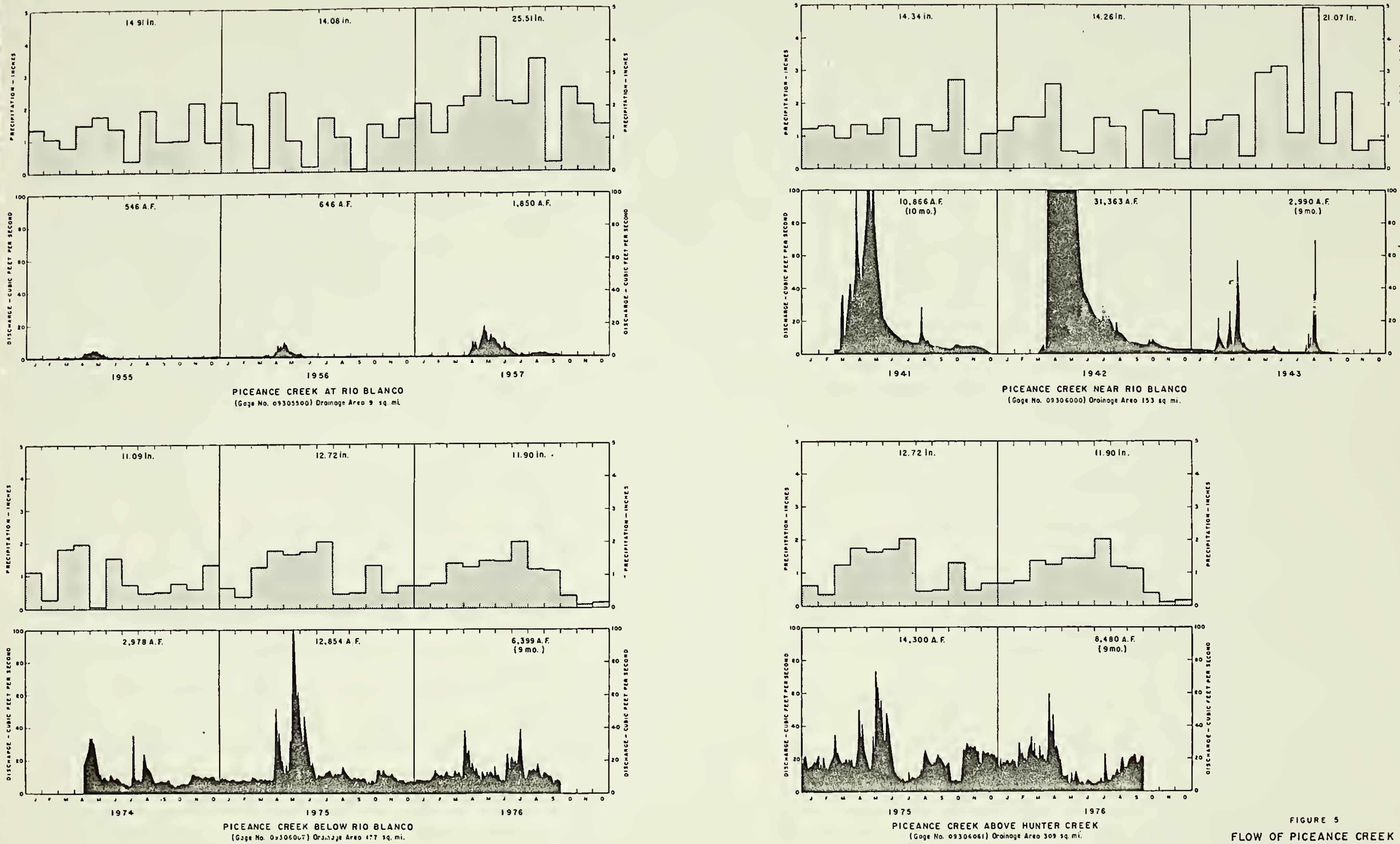
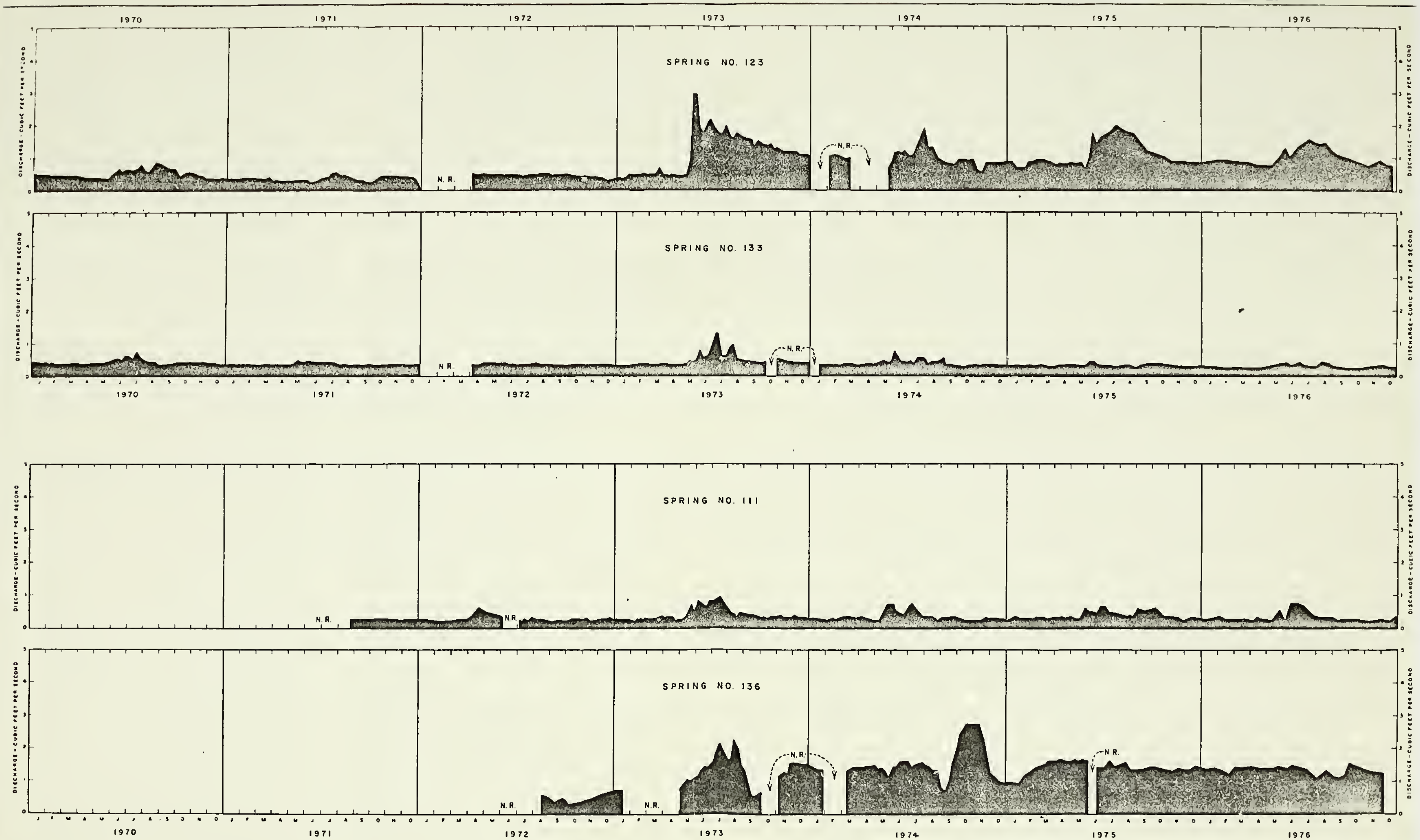


FIGURE 5

FLOW OF PICEANCE CREEK AT VARIOUS STATIONS AND PRECIPITATION AT MEEKER



NOTES

Spring Numbers are those established by the Colorado Division of Water Resources.
N.R. denotes periods of no records.
See Figure 1 for location of springs.

FIGURE 6

FLOW OF SELECTED SPRINGS IN THE PICEANCE CREEK BASIN

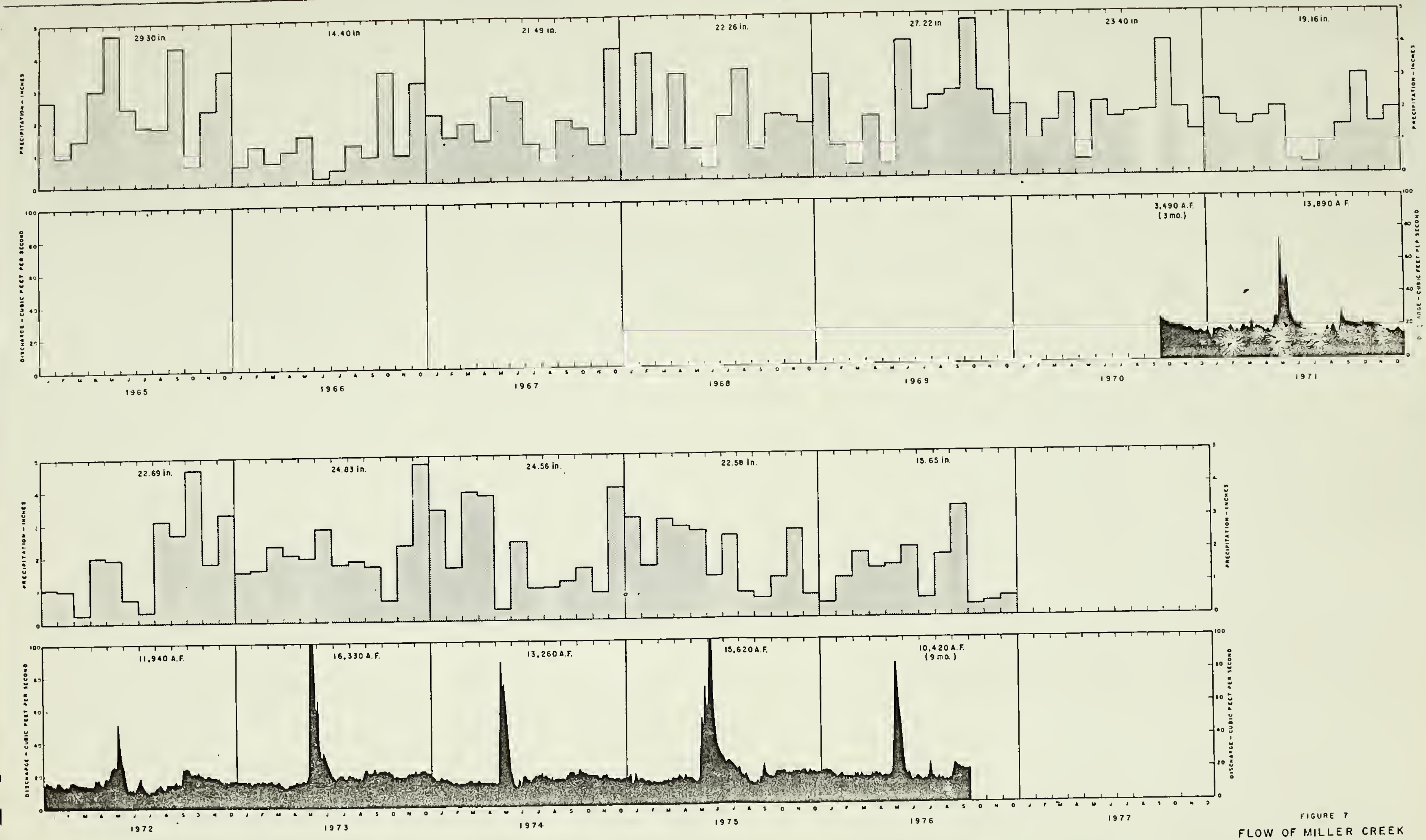


FIGURE 7
FLOW OF MILLER CREEK
NEAR MEEKER
AND
PRECIPITATION AT MARVINE RANCH

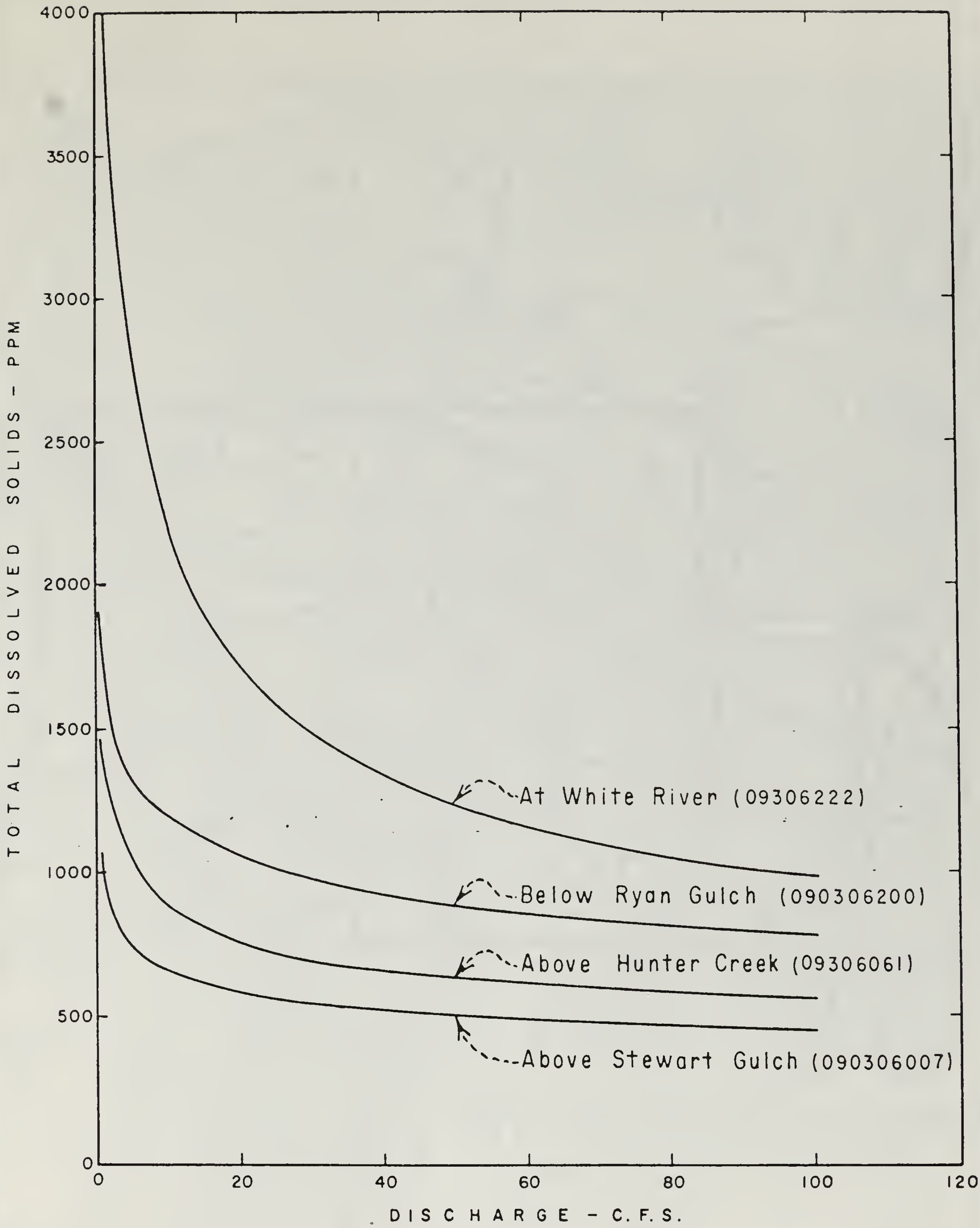


FIGURE 8

QUALITY OF WATER
IN
PICEANCE CREEK

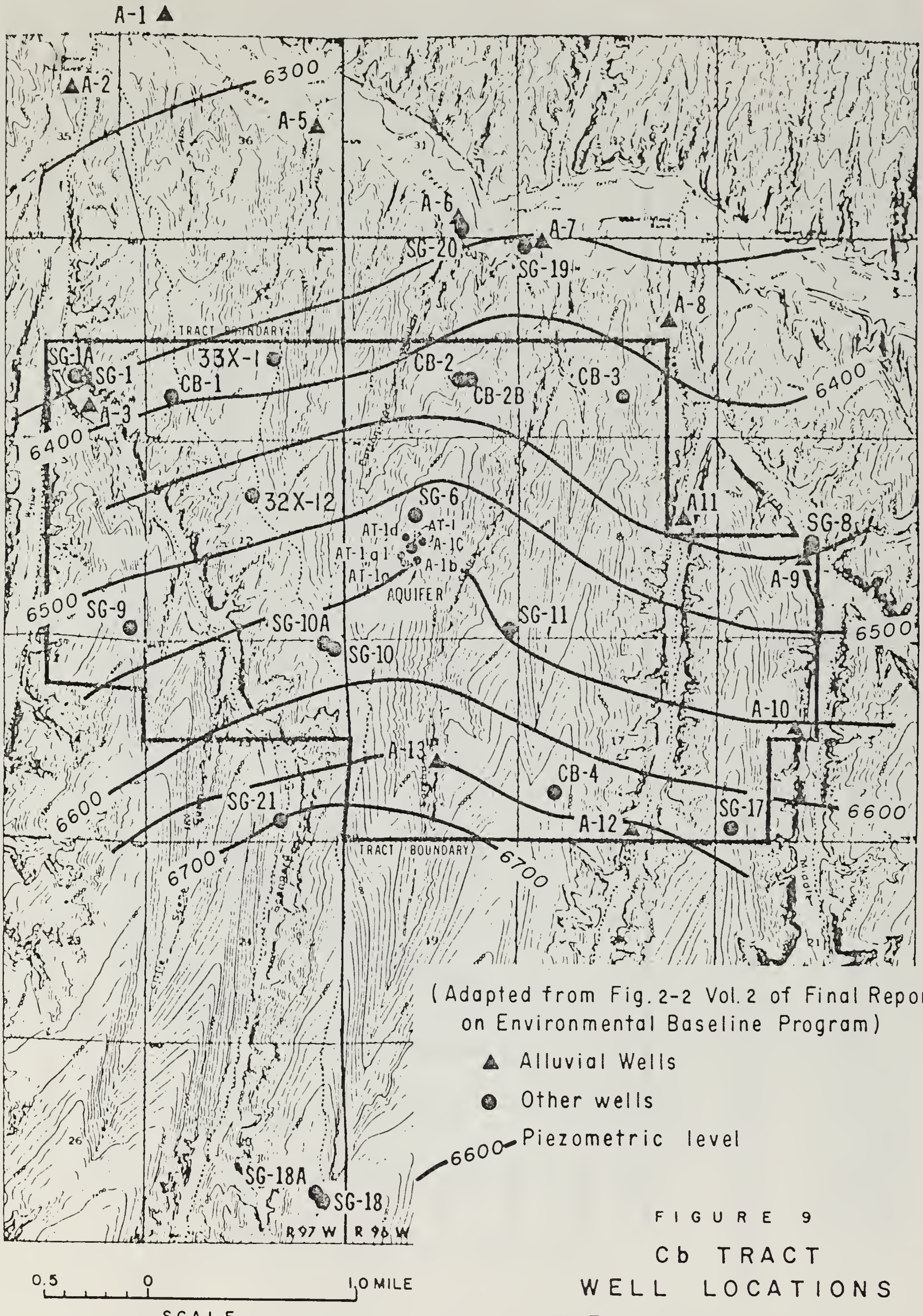
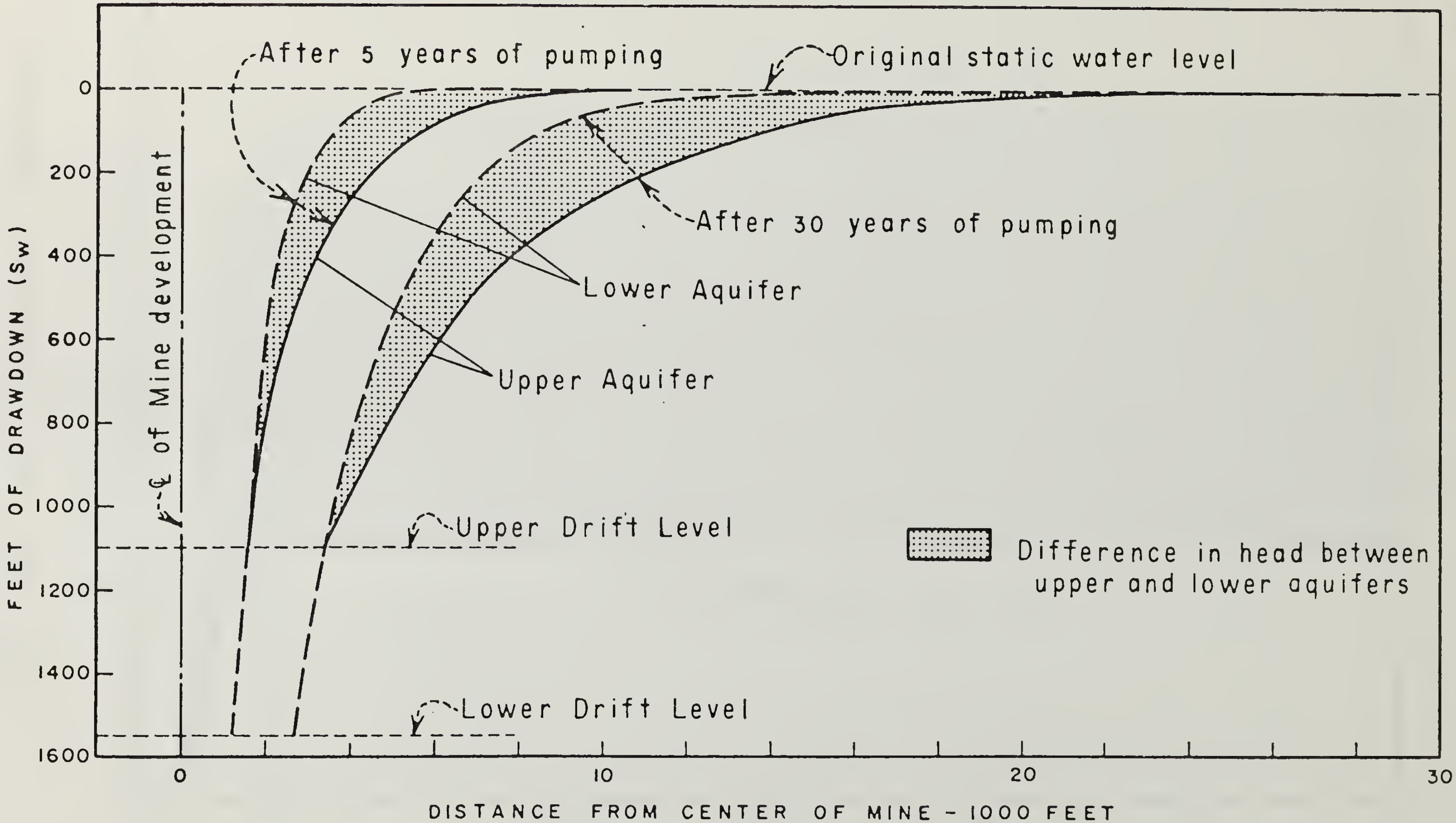


FIGURE 9

Cb TRACT
WELL LOCATIONS
PIEZOMETRIC LEVELS

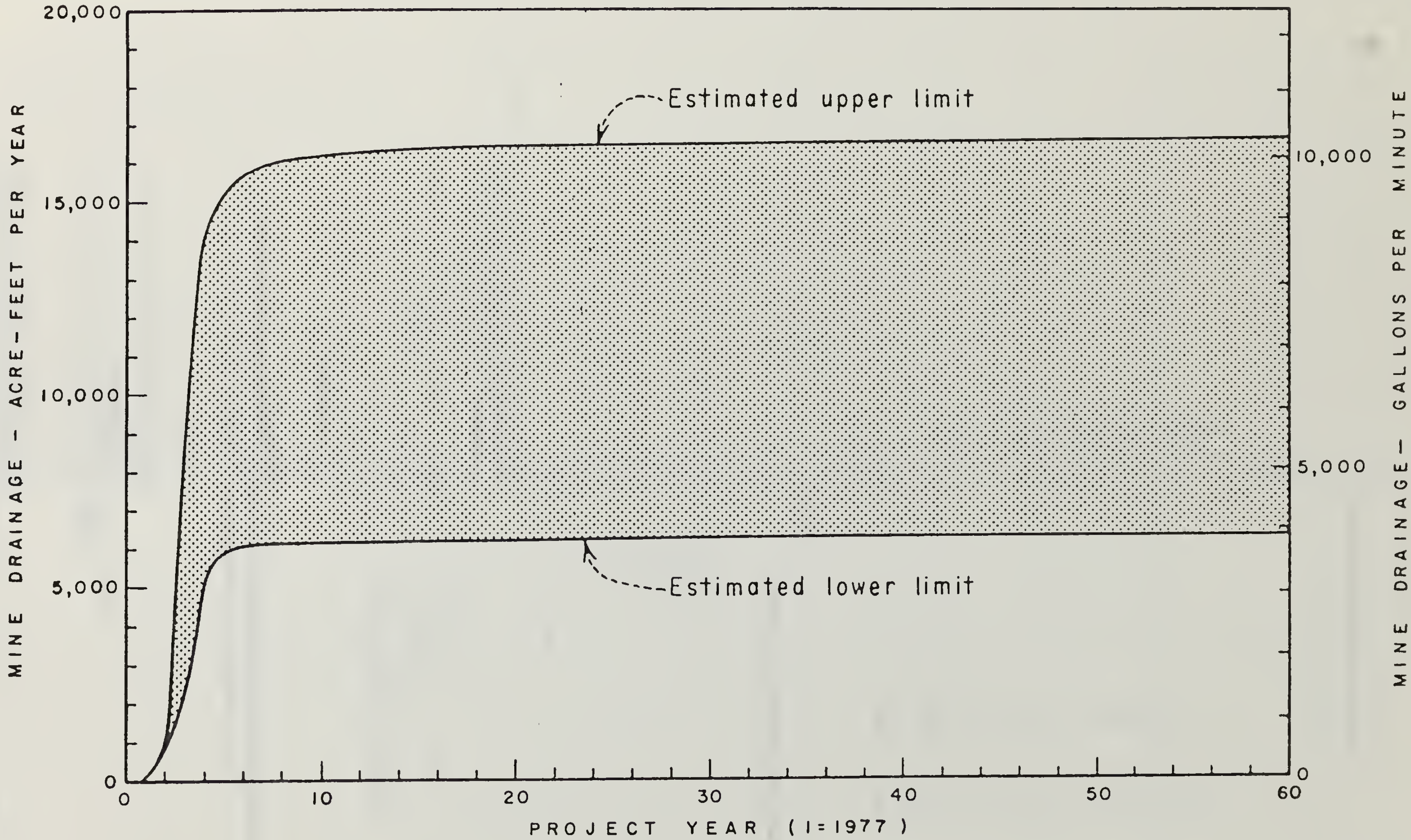


Curves are based on following parameters:

		Upper Aquifer	Lower Aquifer
Transmissivity (T)	gpd/ft.	1500	400
Storage coefficient (S)	-	0.05	0.05
Discharge (Q)	gpm	6700	3700

FIGURE 10

PROFILES OF PIEZOMETRIC LEVELS WITH MINE DEWATERING



Curves are based on following aquifer constants:

	Lower Limit	Upper Limit
Transmissivity (gpd/ft)		
Upper aquifer	1500	1500
Lower aquifer	400	400
Storage coefficient	0.001	0.05

FIGURE 11

ESTIMATED RANGE OF MINE DRAINAGE FLOWS

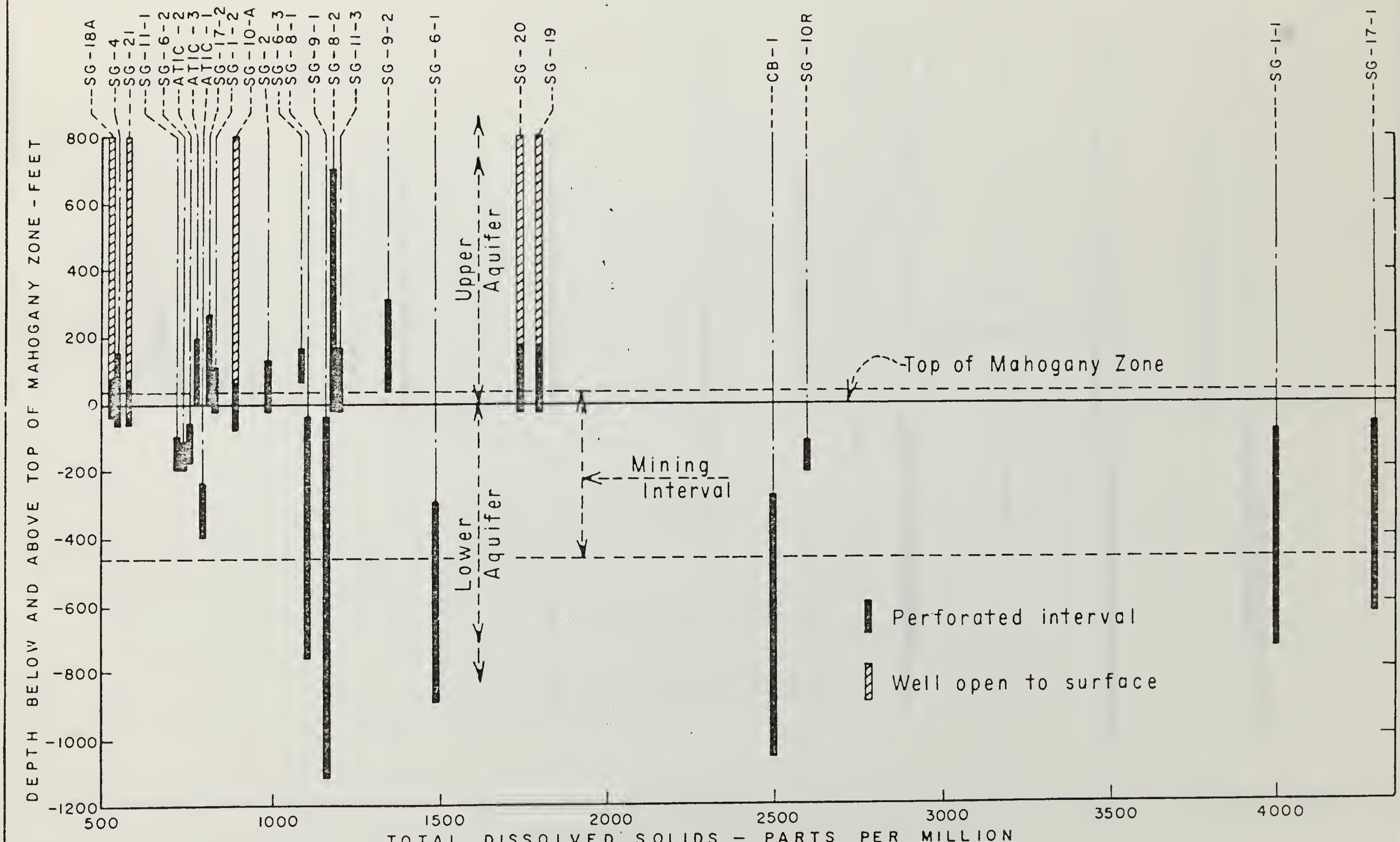


FIGURE 12

TOTAL DISSOLVED SOLIDS IN GROUNDWATER

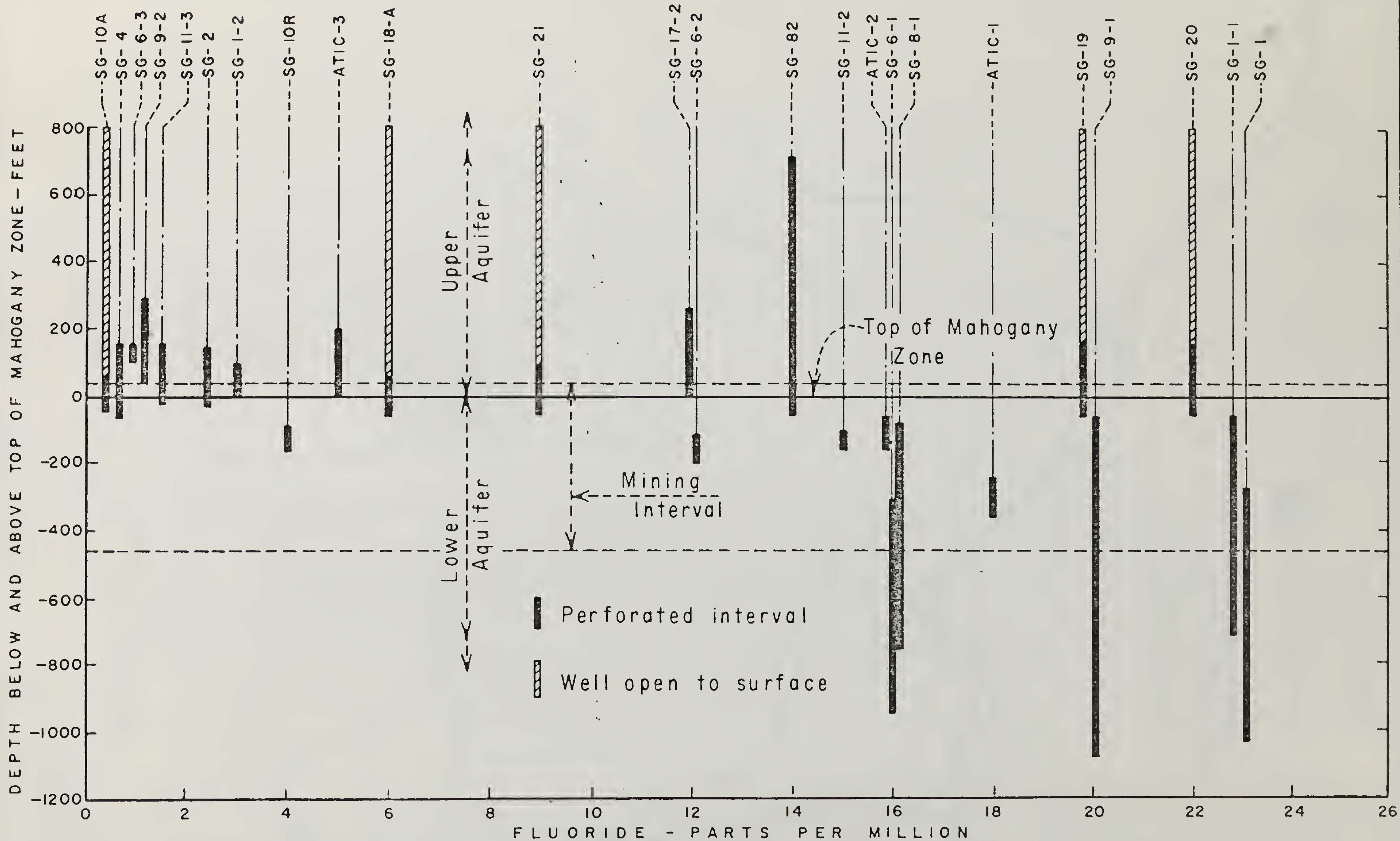


FIGURE 13

FLUORIDE IN GROUNDWATER

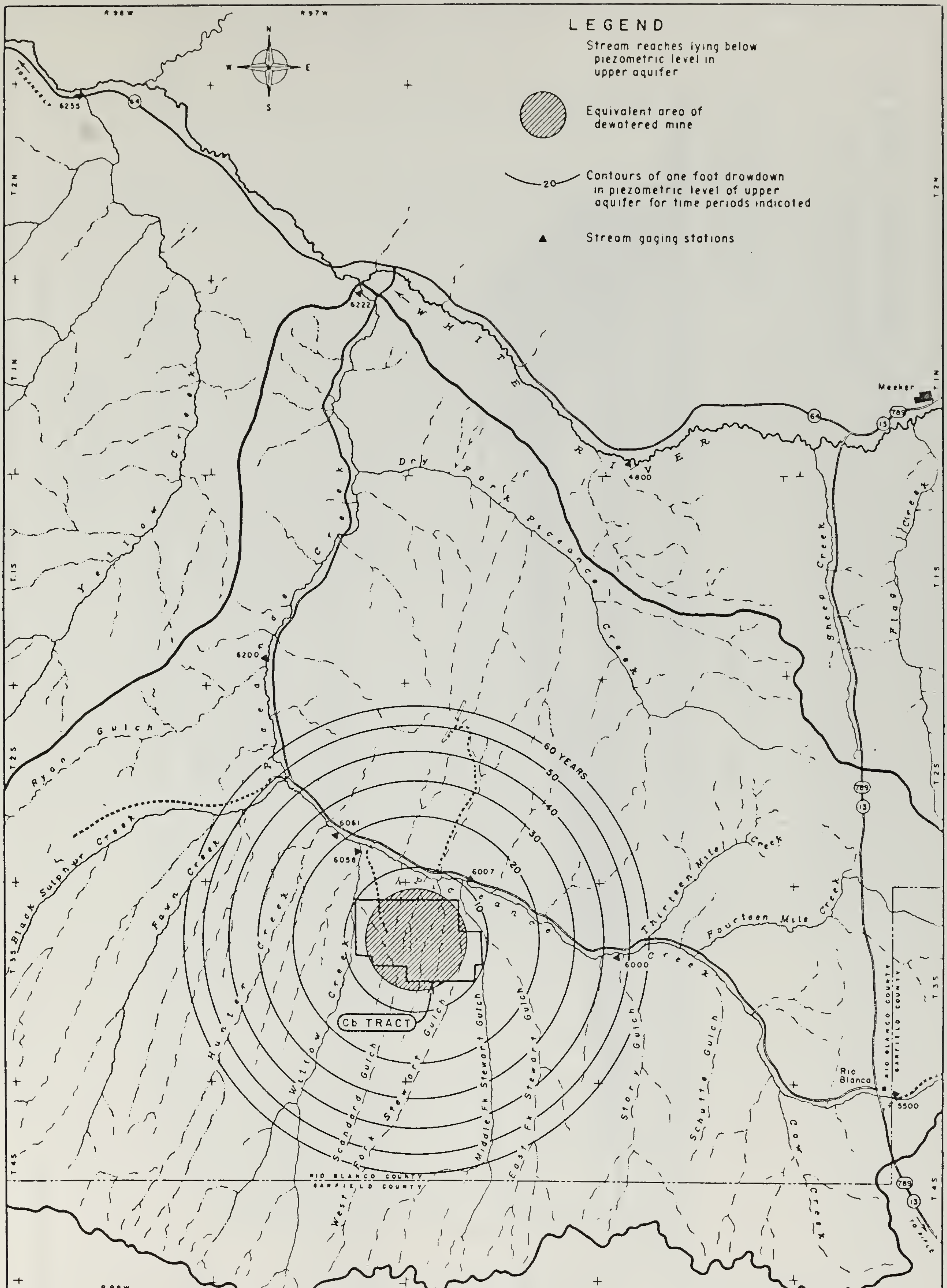


FIGURE 14
ZONE OF INFLUENCE OF MINE DEWATERING

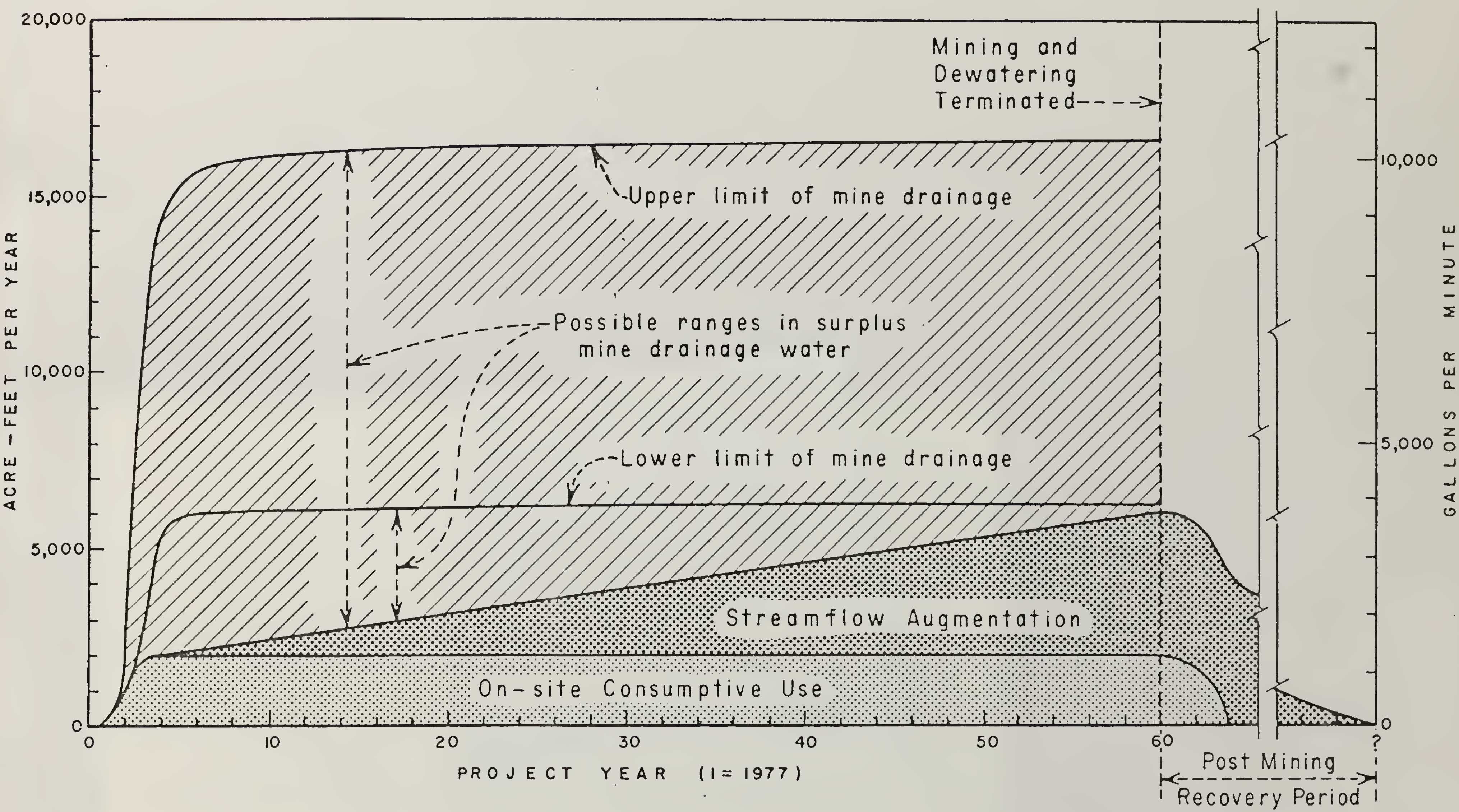


FIGURE 15

DISPOSITION OF

MINE DRAINAGE WATER

DATE LOANED	BORROWER